TISSUE ENGINEERED TEXTILES:

‘Can the integration of textile craft with tissue-engineering techniques lead to the development of a new materiality for future design applications?’

A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy at the University of the Arts London

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Abstract

As early as the nineteenth century scientists were considering the idea that we would be able to manufacture with living materials. What was once seen as a radical notion is now being made a reality in laboratories around the world and is drawing ever greater interest from designers as they realise what the potential offered by biotechnology could mean for future products, as well as regenerative medicine. This thesis presents an insight into how the integration of textile craft and tissue engineering techniques can lead to the development of a new materiality for future applications in both design and science.

This PhD investigates one biotechnology in particular, tissue-engineering, and its impact on how and what we may design in the future. Tissue-engineering is a field that combines multiple disciplines including biology, engineering and material science. The aim of the field is to repair the body, by either improving or replacing parts. As a discipline, tissue-engineering is involved in trying to replicate and engineer structures found within the body, as a result those who design scaffolds need to have an understanding of form and architecture. Through experiments carried out in collaboration with the Tissue Engineering & Biophotonics laboratory at Kings College London, the research has produced scaffolds that demonstrate how cells can use textiles as cues to orientate themselves, how to direct that orientation and how to selectively control growth. The original contribution to knowledge in this research is the untapped possibilities within the realm of the bespoke, customised scaffolds. The PhD has explored the creation of hand-crafted, living, complex, dynamic architectures and utilising traditional textile techniques to produce a final collection of tissue engineered textile scaffolds. Alongside this, it presents new knowledge through the creation of a Materials Archive that provides a resource for future designers working within this emerging discipline.

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CHAPTER 1:
Introduction

"I think the biggest innovations of the 21st century will be at the intersection of biology and technology."
Steve Jobs
(cited by Timmerman, 2011)

1.1 Introduction

This PhD was born out of a long-held fascination with biology and the potential that we could use it to grow our future materials. My research into the field of biofabrication started early in my first year of BA studies, by random coincidence, through being given a copy of Issue 15 of Selvedge Magazine (figure 1.1). Within this specific edition was an article on medical textiles, and it featured a piece of digital embroidery nicknamed 'The Beautiful Snowflake'. The piece, (figure 1.2), is an entirely digitally embroidered medical implant designed for a patient who needed reconstructive surgery in their shoulder after a tumour was removed. The shape looks like a snowflake because the surgeon needed multiple attachment points to stitch the muscles back in place. The reason embroidery was used to create the implant is because you can mimic natural structures found within the body. A knitted fabric would have stretched, and woven fabric is created at right angles and would fray when cut. It was the use of traditional textile stitches that we have been using for millennia, such as satin stitch or running stitch, being used in new cutting-edge technologies that has inspired my own ongoing body of work. It is no exaggeration to say that reading this article, and seeing this particular piece, went on to define my research interests and practice to this day.

Being introduced to the field of medical textiles, and the potential of multidisciplinary working, led to the discovery of a range of artists and designers working with living materials in their own practice. From Oron Catts and Ionat Zurr (collectively known as The Tissue Culture and Arts Project) whose artwork 'Victimless Leather' critically interrogated the notion of the 'victim' and the exploitation of the living by growing a tiny leather jacket in vitro, to the 'Biojewellery' project, by Nikki Stott and Tobie Kerridge, where couples volunteered to have wedding rings grown out of their partners bone cells, through to sheets of pure cellulose grown in vats of liquid - the work of Suzanne Lee's Biocouture™ project. The latter explored bacterial cellulose fermented in nothing more than a sugary green tea solution. Although each of these projects had a different agenda, they have one thing in common - they collaborated with living

organisms to grow the materials or end pieces. This, as an idea, has far-reaching implications and possibilities for how our future material world may well be shaped.

Medical textiles are used within the field of regenerative medicine and tissue engineering. Tissue engineering is defined as 'an interdisciplinary field that applies the principles of engineering and life sciences toward the development of biological substitutes that restore, maintain, or improve tissue function or a whole organ.' (Langer & Vacanti, 1993). In order to repair the body, tissue engineering uses 'a set of methods that can replace or repair damaged or diseased tissues with natural, synthetic, or semisynthetic tissue mimics. These mimics can either be fully functional or will grow into the required functionality.' (nature.com, n.d.) moreover, the living elements that grow these replacement parts are cells, and 'cells are the building blocks of tissue, and tissues are the basic unit of function in the body.' (NIBIB, 2018). My early interest in the development of medical textiles singled out the discipline of tissue engineering as an area for investigation. Initially, the engagement with the technology was from outside of the discipline, as with many designers interested in science, it can be challenging to gain access to expertise or a laboratory. Out of this inability to work within the lab, I developed speculative work designed to explore the potential of the technology. Following on from my MA in Material Futures (formerly Textile Futures) at Central Saint Martins, UAL, I was fortunate to be able to complete a residency at SymbioticA, a unique artistic research department based at the University of Western Australia. Run by Oron Catts and Ionat Zurr, it allows artists and designers to complete residencies in the sciences. In the summer of 2011 I spent three months learning the necessary lab skills involved in the science of tissue engineering. It was this experience that helped considerably when finding a laboratory to partner with for my subsequent research.

The residency also cemented the decision to pursue a PhD in the subject area. For the simple reason that I believed, and still do, that living materials are going to cause a paradigm shift in what and how we make in the future - and if this is the case, as designers, we should be involved in that development. If these technologies hold the potential to be more sustainable than current processes and materials, then both critically, and practically, we need to learn how to design with them to explore the implications. I could have gone straight into the job market after my masters degree, however no 'tissue-engineered textiles' industry existed at the time. Instead I felt more research was necessary, so I embarked on this PhD to build upon the existing work in the wider field and anticipating future career opportunities both in and out of the

laboratory. The field of biofabrication for consumer applications has been rapidly developing. In the interim, between starting and completing the PhD, a range of biofabrication companies have been founded. It was due to my unusual research background that I was offered employment initially as Senior Materials Designer, and subsequently as Associate Director of Materials Design at Modern Meadow, a biotech startup based in New York. The role was unique as it required a designer to be embedded in the laboratory alongside scientists, a position which I've held for the last three years. Whilst these types of positions are still very few in number, it does demonstrate the value brought by having a design voice involved from the start of the development of a new material. The traditional divides that have existed between the disciplines of science and design are being dismantled with ever greater realisation of the importance of bringing in those who understand the product from the very beginning of development. (Kapsali, 2016, p.15).

Initially having had a practice based on speculative work, and in presenting possible futures, the original intention of this PhD was to criticality explore the implications of working with living materials. Reflecting this, the original research question was: "How can the integration of textile practice and tissue-engineering enable us to critically engage with the implications of what it means to work with living materials in design?" As the research developed throughout the PhD, the discipline of speculative design became less relevant to me personally and to the research as a whole. I wanted to understand where the technology is currently, and what my skill set could bring to its development. This prompted a change in research question: "Can the integration of textile craft with tissue-engineering techniques lead to the development of a new materiality for future design applications?". Craft, and the notion of what the hand and making can bring to technology, became the driving force behind a body of research that looks at how we can develop both the fields of regenerative medicine and future consumer products. Outcomes that view living materials, and the technologies that create them, as systems that need understanding holistically in order to discern their implications and future potential.

Figure 1.1
Selvedge Magazine, pages from issue 15 'Wellbeing' (Selvedge, 2007)

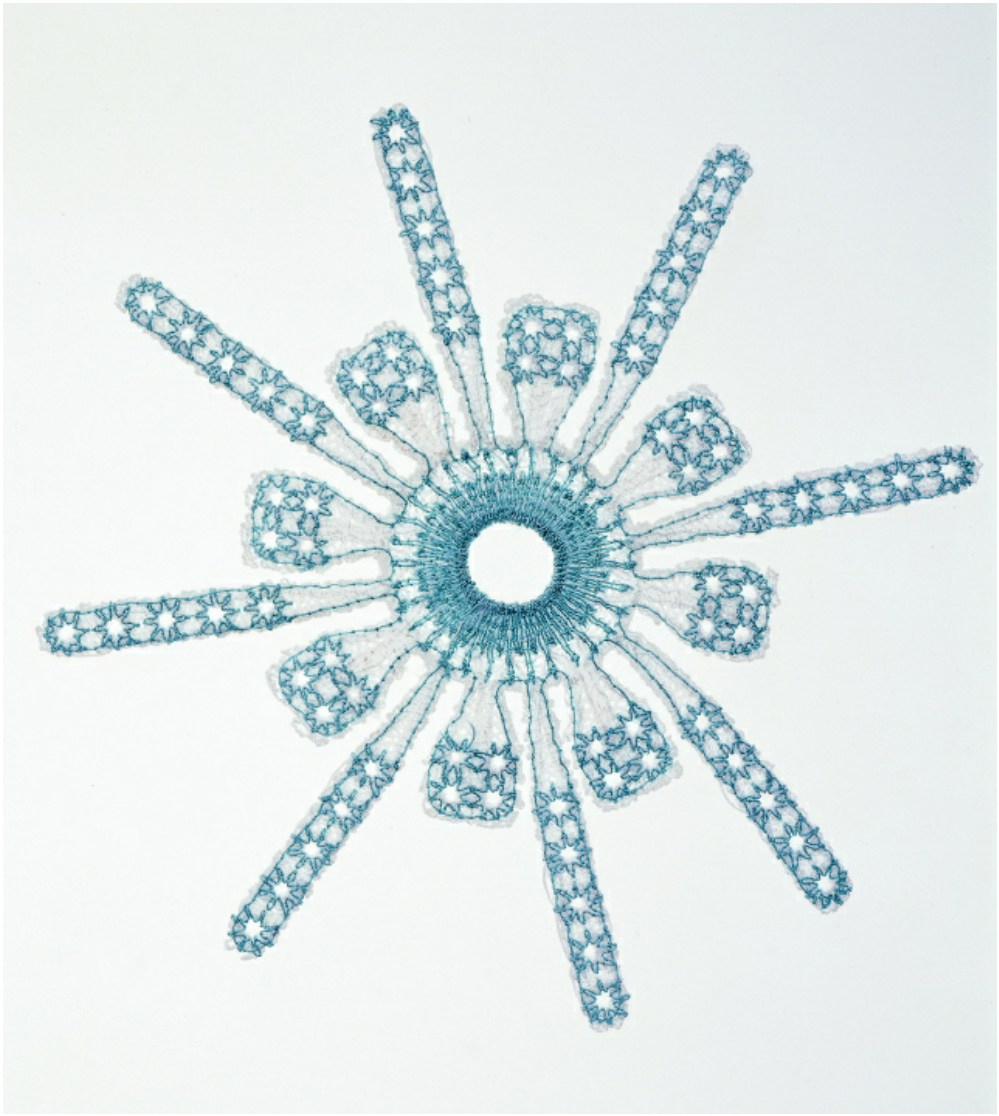


Figure 1.2
Ellis Developments, 'Beautiful Snowflake'
(Ellis Developments, n.d.)

1.2 Research Model & Methodological Approach

As a designer embarking on a PhD, in the very beginning it felt as if I was spending half of my time attempting to conduct the research I had set out to do, and the other half of the time researching to try to understand and articulate what it was I was doing - especially from a methodological standpoint. It seems this is a common problem for many practice-based design PhDs. There are several possible reasons why this is the case; firstly, practice-based design PhDs are relatively 'young' and have not had the time to develop into a fully matured area of academic research. Secondly, and perhaps most importantly, most creative training (mine included) does not ask that the designer explicitly describe their methodology - it is most often something that is unspoken and instinctual. To corroborate this point I came across a video of a fellow PhD student, Stoffel Kuenen, who chaired a discussion session as part of the 2014 Design Research Society conference, at Umeå, Sweden. The premise of the conversation for Kuenen was to try and unpack "how I am going to do my project in design research?" (Kuenen, 2014). He goes on to talk about the question of how to structure what it is you intend to do:

> For sketching out the direction that I was going to take and what kind of structure I was going to follow in this project I looked to literature, to discourse, on practice-led design research/ constructed design research and it struck me that most of the discourse is about the forms and formats that we publish our work in. [...] But very little is said about how we project it, how we set it up, how we carry it through - from an idea to some kind of result.
>
> (ibid)

To help answer some of his questions, he put them to leading researchers in the field including Caroline Hummels, 'Full Professor in Design and Theory for Transformative Qualities', Technische Universiteit Eindhoven. The first question asked was 'What do you do?' to which she replied, "I thought you were asking simple questions!" (ibid). This humorous off the cuff remark is indicative of the way most designers feel when asked to describe what they do, let alone when asked to commit it to writing. There is also the potential added complication that the PhD may not involve a continuous body of practice, which is the case in this research - there have been numerous projects that have fallen under the umbrella of the PhD. Each is different in some way from the next, subsequently each has their own methodology.

With the above taken into account, this section of the introduction aims to bring a level of specificity to the research model and methodologies used. During the 1990s, a range of different research papers were published by the Royal College of Art, London, which discussed the topic of design research. One of the most cited papers published as part of that series was

by Christopher Frayling entitled ‘Research in Art and Design’. In it Frayling describes three distinct types of research: ‘research into art and design', ‘research through art and design' and ‘research for art and design' (Frayling, 1993, p.5). The difference between the types is defined as the following:

> Research into design is a study of design as a discipline. It involves activities such as "historical research, aesthetic or perceptual research, and research into a variety of theoretical perspectives" including "social, economic, political, ethical, cultural, iconographic, technical, material, structural" etc.
>
> Research through design is described as "materials research", "development work - for example customising a piece of technology to do something no one had considered before", and "action research" based. It is where the knowledge is created through design practice.
>
> Research for design is defined as research "where the end product is an artefact - where thinking is, so to speak, embodied in the artefact, where the goal is not primarily communicable, but in the sense of visual or iconic or imagistic communication.
>
> (Frayling, 1993, p.5)

Following these definitions, the majority of this Phd's projects fall under ‘research through design', where the majority of knowledge has been developed through the ‘doing' of the work. It is embodied knowledge, derived from the act of making, be that the speculative work or the laboratory-based practice. However, some of the projects sit under the ‘research for design' umbrella or traverse the two. For example, artefacts made within the discipline of Speculative Design can be argued to be made almost solely to embed the thinking behind them, with the ultimate aim of communicating ideas to an audience. In the case of this PhD, they generated knowledge in their creation and were designed to communicate knowledge as conceptual prototypes. Also, under the term ‘research for' are the artefacts created for ‘Haute Bacon' collection (Chapter 4) which are described as a "Super-Object":

> The super-object stands as a metaphor for craft as an independent practice, for a body of objects that grow out of design because they have a form-typological relation to functional objects, even as the objects' artistic (aesthetic or conceptual) content is central.
>
> (Mazanti, 2011, p. 62)

The ideas embedded within many of the artefacts made during this PhD are central, with much of the knowledge generated through the making of them. This movement between definitions is perhaps indicative of a multidisciplinary way of working, where the design challenges we face are ever increasingly ‘wicked problems' (Buchanan, 1992).

Finally, research carried out in this PhD can also be described as ‘constructive design research' (Koskinen, et al., 2011, p. 5) - defined as ‘design research in which construction – be it product, system, space, or media – takes centre place and becomes the key means in constructing knowledge’. This concept of construction can also be found in the writings of Estelle Barrett and her argument that one of the crucial elements of practice-based research is its subjective nature that generates situated knowledge. ‘Subjective approaches in artistic research are implicated in and give rise to a second feature of practice as research: its emergent methodologies. Martin Heidegger's notion of "praxical knowledge" [...] implies that ideas and theory are ultimately the result of practice rather than vice versa.’ (Barrett, 2010, p. 6) This research aims to allow situated practice, working with tissue-engineering, to develop new theory and knowledge.

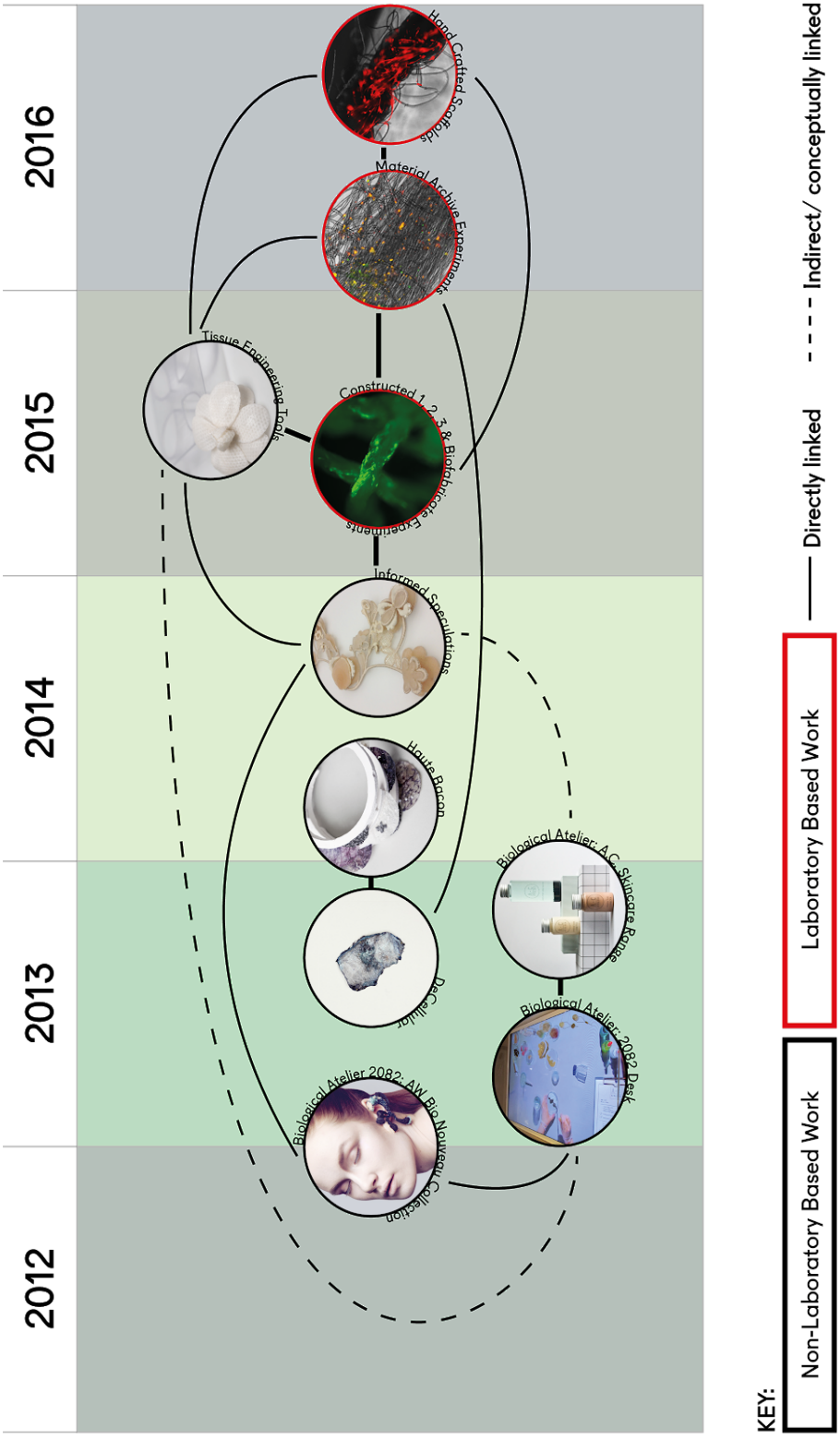


Figure 1.3
Practice Map & Timeline

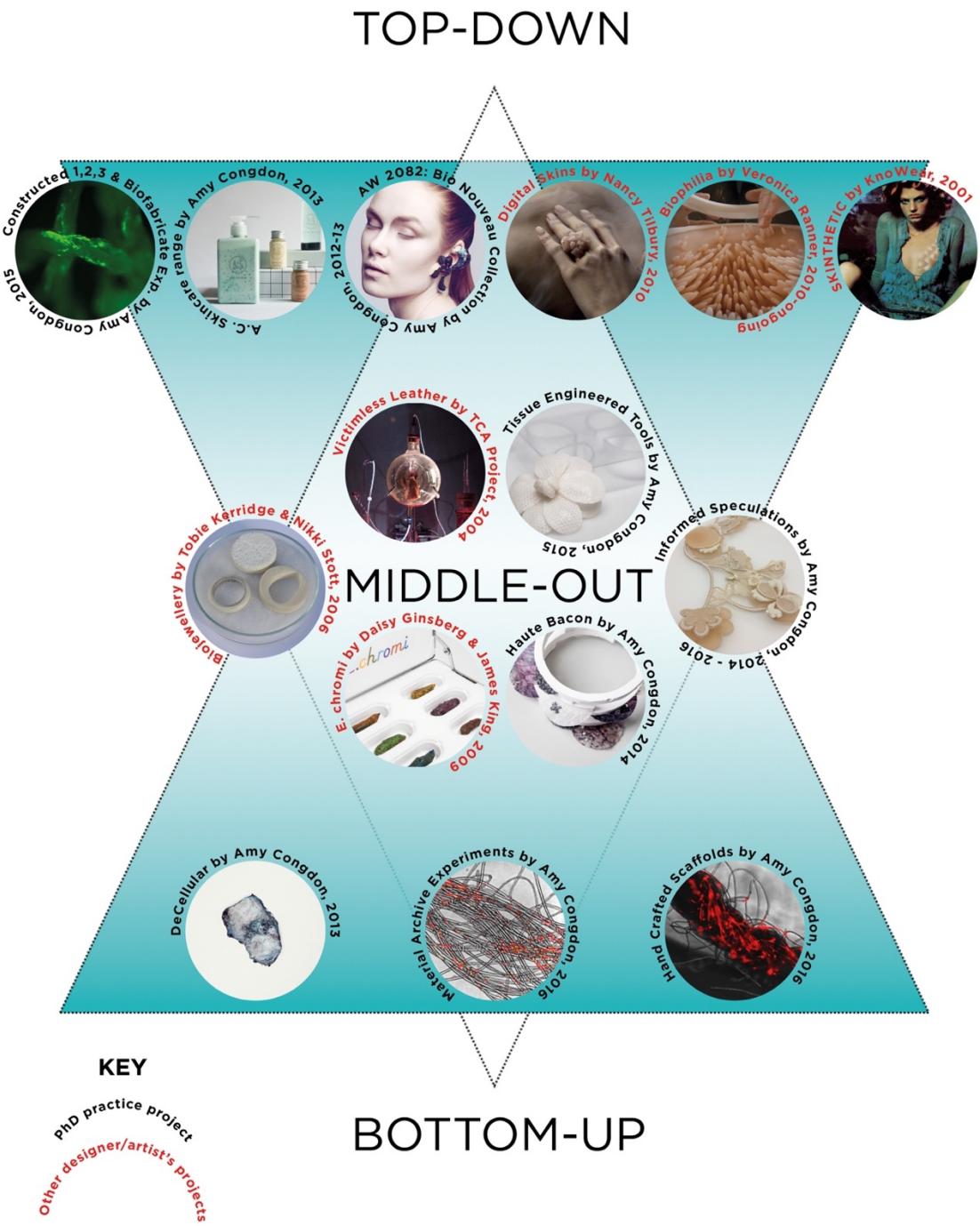


Figure 1.4
'Top-Down', 'Middle-Out' & 'Bottom-Up' Practice Mapping

Because of the varying nature of the PhD's practice it relies on a range of methodologies; every project has a unique approach, with each detailed in the relevant chapters throughout the thesis. However, through the development of the work, two distinct methodological approaches have been significant. They are ‘top-down' and ‘bottom-up' (see figure 1.4). These are two terms that I have used instinctively for a long time in association with my practice. A third term ‘middle-out' is also described below, but much less frequently used and is an amalgamation of the other two approaches. Figure 1.4 (above) groups all of the projects developed during the PhD, as well as some prominent contextual examples, by their high-level methodological approach. What is evident is that the majority of Speculative Design work falls into ‘top-down', such as the ‘SKINTHETIC' project by KnoWear that explored what technologies might be used to brand bodies in the future. The more craft-led explorations, such as those based in the laboratory, the Materials Archive and subsequent scaffolds, are labelled as ‘bottom-up' due to material experimentation driving the end goal of the projects. How each project was categorised is determined ultimately by whether the end object/ product is identified from the beginning, or it emerges through experimentation with materials.

Through research, there seems to be little in the way of academic literature discussing these terms in relation to design. They are used by Knippers and Speck to specifically describe ‘[p]rocess sequences in biomimetic research’ where bottom-up is described as ‘biology push’ and top-down as ‘technology pull’ (2012, p. 6). The use of the phrases ‘push' and ‘pull' in this instance seem to have much to do with the theory of "demand pull/ technology push" developed by Joseph Schumpeter and Jacob Schmookler in the middle of the twentieth century (Coombs, Saviotti and Walsh, 1987, p. 94-5). However, the predominant history of terms appear to be in nanotechnology, computer programming, software development, management and engineering. When described in the engineering discipline, they are defined as the following:

> Top-down: Begin with the design criteria and create components that meet those criteria. Bottom-up: Place existing parts and subassemblies into an assembly file; positioning components by applying assembly constraints.
> Middle-out: Usually, you begin with some existing components and design other parts as required.
>
> (Knowledge.autodesk.com, 2016)

Both of these definitions are based on assumptions that the designer/ engineer knows what he or she is going to make as a final outcome. This thesis's definition differs. A ‘top-down' methodology is based on the end application, outcome or product already being known - for

example, you know you are going to end up with a chair. Your task is then to design the chair; identifying a design direction, the best materials, processes and techniques with which to achieve the end goal. In contrast, ‘bottom-up' is defined here as a project where the end application, outcome or product is not known - for example, you want to understand what the properties are of a specific material. Your task is then to sample and experiment extensively with the material to understand its capabilities and limitations, and from this knowledge you can identify the best end application for it. Both processes end up with an outcome but differ significantly in how they achieve it. ‘Top-down' could be argued to be a more product design type of approach, whereas ‘bottom-up' is how I would classify the majority of craft practice. Generally speaking, ‘top-down' can be described as more prescriptive or deterministic in its approach, whereas ‘bottom-up' is concerned with creating emergent knowledge. The latter has been the most impactful way of working during the PhD. When the practice was genuinely experimental, the opportunity for discovery and the unexpected was far more prominent. The methodology developed (figure 1.5), and discussed further in chapter 5 of this thesis, takes these redefined terms of ‘top-down' and ‘bottom-up' as a basis for a new model for using textile craft practice in the development of new structures for tissue engineering.

In a paper on new methodologies in art and design research, Alex Seago and Anthony Dunne present the case study of a metalsmith, Ian Ferguson, who was confronted with being a maker embedded within a scientific research environment. Despite this, Ian Ferguson developed ‘a research strategy in which metallurgical research techniques were interpreted from the viewpoint of the producer of craft objects. As an experienced metalsmith, Ferguson's practical understanding of the behaviour of materials is considerable, but the focus of his research on the application of solid state diffusion bonding is radically different from a research metallurgist who would usually lack the craft person's understanding of the creative process. Ferguson's research is particularly interesting for the way in which it combines an understanding of the processes of production of materials with a very high level of craft skill in the production of aesthetic objects.’ (1999, p. 2). The documentation of this case struck a chord with my own approach to working within the tissue engineering laboratory as someone coming from a craftsperson's bottom-up understanding of materials and processes.

> In Being and Time (1996) Martin Heidegger sets out to examine the particular form of knowledge that arises from our handling of materials and processes. Heidegger argues that we do not come to "know" the world theoretically through contemplative knowledge in the first instance. Rather, we come to know the world theoretically only after we have come to understand it through handling. Thus, the new can be seen to

> emerge in the involvement with materials, methods, tools and ideas of practice. It is not just the representation of an already formed idea nor is it achieved through conscious attempts to be original.
>
> (Barrett & Bolt, 2010, p. 30)

What developed through the later stages of the work at Kings College London was a bottom-up, craft-centric approach to scaffold making (figure 1.5). This approach was one that was based first and foremost on an understanding of materials and processes. This understanding could then be translated to any number of outcomes - from the medical to the commercial. In essence, the beginnings of a craft system for tissue engineering. This way of working, where the properties and behaviours of a material are the starting point of the process, is also being used by others working in the field (Karana et al., 2019, p. 41), where the characteristics of the material dictate the end product or outcome and what application it is best suited to.

There is undeniable freedom in the approach of a designer or craft practitioner, one that is not always enjoyed by grant-funded research scientists who are bound by various criteria and limitations of funders. However, this thesis argues that there is also an inherent difference in the approach. Nigel Cross articulated this difference: 'These experiments suggest that scientists problem-solve by analysis, whereas designers problem-solve by synthesis.' (Cross, 1982, p. 5). The experiments he is referring to is how professionals from different disciplines problem solve. I have found that through synthesis, I was able to take the information on cell behaviour concerning specific protocols on certain materials, and combine this information into a scaffold. "The practical knowledge at the heart of textile design and production processes is acquired through the physical manipulation of materials. [...] Through the constant handling of the 'stuff' of textiles and the repetition of the gestures of making, the practitioner's senses work together to build a comprehensive embodied understanding of both materials and process." (Kane and Philpott, 2013, p. 6). Through a textile maker's understanding of structure-property relationships, I was able to understand how cells grow on an individual fibre and how that could affect their growth on a yarn and ultimately the finished scaffold.

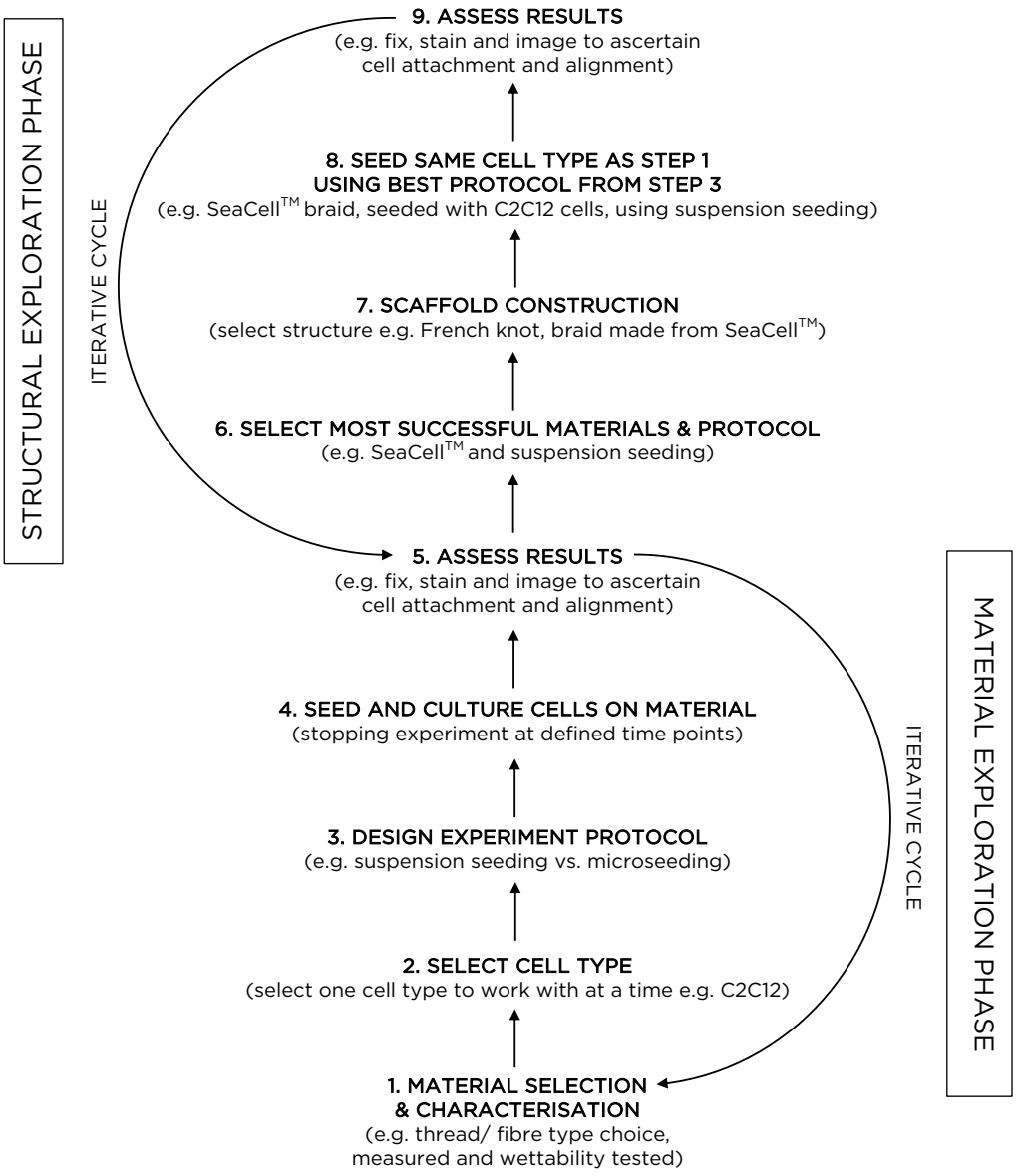


Figure 1.5

Diagrammatic of 'Bottom-Up' methodology developed during laboratory

1.3 Aims & Objectives

This PhD's aims are listed below, each with their corresponding objectives.

Aim 1:

To produce an innovative body of work that articulates the complex implications of utilising biotechnology for textile design practice.

Note: This aim, defined at the beginning of the research project, was articulated in relation to the original intention to be much more future-focused in the research, with less emphasis on what is currently achievable in the laboratory. It has still been included as an aim because it specifically relates to the early Speculative Design work of the PhD.

- Define what critical practice, and specifically Speculative Design, means in relation to this research
- Develop a new collection of speculative prototypes which present a possible future for Haute Couture constructed from materials ‘grown' in the laboratory
- Identify the potential, as well as the limitations, of this approach in communicating possible product futures

Aim 2:
Develop a body of work which demonstrates what is achievable through integrating a textile-based craft approach into the discipline of tissue engineering.

- Identify and establish a relationship with a tissue engineering laboratory
- Develop an understanding of the methods and tools used in tissue engineering
- Use a textile craft approach to rethink and redesign the processes and tools of tissue engineering
- Design, seed and iterate through the creation of a range of textile scaffolds
- Identify and articulate the value of having a textile craft practitioner based in the tissue engineering laboratory

Aim 3:
Create a Materials Archive as an entry point, and resource, for other designers wishing to work in the field - alongside a range of scaffolds that have applications for both regenerative medicine and future consumer products.

- Identify and characterise a range of materials to seed with cells
- Seed the different materials and record the results of the experiments in a format that is a resource for others looking to enter the field
- Develop a range of scaffolds based on the above
- Articulate the implications of the practice - how a textile methodology can inform tissue engineering and what the logical next steps of the research would be

1.4. Summary of thesis content

This final section of the introduction details the contents of the thesis chapter by chapter.

Chapter 2

This chapter is designed to set the scene for the research, aiming to layout what is currently happening in the field of tissue engineering and regenerative medicine, and outlining what role design can play in its development. The lens of textiles is applied to bring a level of specificity

to a large and complex field. It reviews the past, current and future tissue engineering practices using textile techniques in their application. As the chapter develops, there is a section discussing the field of living technology, its implications, and how it is increasingly being looked to by design as a means to develop new materials and products. It defines this thesis's definition of living technology, and the debate around its use - a conversation which is pertinent to all areas of design. The final section of the chapter introduces craft and its relevance to this research. It explores craft theory and its relationship to working in the tissue engineering laboratory and argues for the importance of material and tacit knowledge. It also looks at the notion of the hand in the lab and elaborates on how making can be a vital tool for understanding such sophisticated technologies whilst they are still in development.

Chapter 3

This chapter presents the speculative design work undertaken at the beginning of the PhD and discusses how this developed the research prior to the practice relocating itself in the laboratory. It covers the history of speculative design, the definition of the field, and the relationship to this PhD's practice. Focusing on work carried out in the design studio, this chapter centres on the speculative *Biological Atelier* projects that shaped the beginning of the research. The chapter discusses the different approaches and definitions of critical design practice mapping the *Biological Atelier* projects to other approaches in this field. It also presents the importance of image-making in Speculative Design, and of contextualisation - through the discussion of the *ALIVE Atelier Desk* and the *AC Atelier Cosmetics* range. It covers the methodologies used and the potential for both informing, and misleading, the general public. Finally, the chapter discusses some of the criticisms of speculative design practice, as well as it's potential and limitations in predicting our material and product futures. It asks the question - in the current cultural climate, 'how responsible are we for the futures we promise?' Overall this chapter looks at the opportunities opened up by using design as a vehicle for debate and education around emerging technologies, whilst also discussing the limitations and implications of this approach.

Chapter 4

This chapter explores how the research developed from the top-down speculative design projects, covered in chapter 3, to the integration of tissue-engineering techniques into the discipline of textiles and vice versa. The first projects discussed are the material archive *DeCellular* and the resulting *Haute Bacon* jewellery collection. The chapter looks at a range of material explorations that reappropriate techniques associated with tissue-engineering and their re-situation to within the designers' studio. It discusses the value of inverting skill sets and processes to achieve unexpected outcomes. The chapter then goes on to cover the initial

work within the laboratory at Kings College London, expanding on the ethical implications of the research relating specifically to work conducted. These are explored both practically from a legislative standpoint, and also philosophically as we contemplate a future where our materials could grow in the laboratory. Following on from this, the chapter covers the first experiments: from the methodologies employed in the design of said experiments, the processes involved, the results, and the next steps for the practice. It discusses the problems and opportunities uncovered through the hands-on work in the laboratory and presents the learnings which went on to inform subsequent experimentation.

Chapter 5

This chapter covers the shift that occurred in the laboratory practice of the PhD, contrasting a bottom-up craft approach to that of a top-down engineering process. It describes what this thesis's definition is of the terms 'top-down' and 'bottom-up' specifically concerning tissue engineering. It re-asks the question: 'what does a textile craft methodology bring to the tissue-engineering laboratory?' The focus then shifts to the concluding laboratory work, documenting the development of the *Materials Archive* - a design-led material collection intended to be a new resource for the creation of both new products for regenerative medicine and future consumer applications. It presents the material selected, the techniques and protocols developed, and the research findings. The archive is a new contribution to the field, created as a resource for designers interested in engaging with living materials in design. Developing out of the *Materials Archive*, was a range of handcrafted scaffolds which explore how different textile structures can control the orientation of cell growth. The other key findings that emerged from the research were the importance of scale, bio-selectivity, and directionality of growth. Finally, the difference in how things are 'proven', in science vs design, is discussed alongside the practice of keeping a lab notebook and recording results. To conclude, the chapter touches on the implications of the research and next steps.

Chapter 6

This final chapter presents a range of tools designed specifically for a textile designer working in a tissue-engineering laboratory. Tools designed in response to the existing tools, and their limitations, and how we might reconceive manufacturing processes within the laboratory. It also documents the creation of a range of 'informed speculations', produced throughout the laboratory work. These specific speculations were designed to communicate feasible future materials and products and are all directly informed by knowledge gained after hands-on work with the technology of tissue-engineering. The chapter also discusses the communication of the laboratory work, from the material archive design through to the illustrations of the most

successful scaffolds and the creation of a behind-the-scenes film. The chapter concludes by outlining the shift in language, and framing, of the research, from that of a platform technology to a system. It explores the value brought by a more inclusive and holistic approach; both on a practical level in the laboratory, and on a macro level for the entirety of the research.

1.5 Conclusion

This chapter introduced the driving forces behind the research, why they matter, and how it came about. It presents the trajectory of the PhD, how its focus shifted during the research, and contextualises it in the field of tissue engineering and textiles. It outlines the research model of this practice-based PhD, and discusses how the projects developed can be defined as both research *through* design and research *for* design. Due to the multi-project nature of the PhD, two overarching methodological approaches are outlined: 'top-down' and 'bottom-up', as well as how they have been employed in the research. The aims and objectives of the PhD are identified, and the structure and contents of the thesis introduced. The next chapter continues the introduction's contextualisation of the research and the multiple fields in which it finds itself situated.

CHAPTER 2:
Our Biotechnologically Crafted Future: working with living materials in design

2.1 Introduction

> 'To truly understand a thing you have to make a version of that thing'
>
> (Dormer, 1997, p.18)

This chapter is intended to set the scene for the research, laying out what is currently happening in the field of tissue engineering and regenerative medicine, and outlining what role design can play in its development. Throughout the chapter a textiles perspective is provided to bring a level of specificity to a large and complex field. As the chapter develops, the notion of the hand in the lab is explored, establishing how making can be a vital tool for understanding these sophisticated and radical technologies. The research fits into the emerging field of biofabrication within design.

> Biofabrication, originally a biomedical definition, today imagines a world of material manufacture where future consumer products are designed and grown harnessing biological organisms. This is a new design paradigm centred on cultivating materials with living cells. Organisms such as yeast, bacteria, fungi, algae and mammalian cells are fermented, cultured and engineered to synthesize natures materials but with new functional and aesthetic properties. They share one key element: life.
>
> (Lee, 2015)

A growing number of designers are turning to working with living materials and collaborating with scientists to develop a new, more sustainable design paradigm. In this research, the living materials in question are cells and there are a set of ethical and cultural questions that surround their use. These issues are discussed in this chapter's final section that looks at living technology, and the debate around its usage, which is pertinent to all areas of design.

As the title suggests, this section of the thesis draws together the three principal components of the PhD: tissue engineering, textile craft and living materials. At the heart of this chapter are materials, their manipulation, and the value placed on them by society and commerce. What makes this a more controversial subject is that the materials in question are living. Many argue that the continually evolving technologies of the life sciences will bring about a paradigm shift in the way we will make. As scientists begin to design with the raw materials of life there is a pressing need for designers to be involved. The real challenge, however, is how to explore the

potential impacts, while also engaging with technologies that promise a radically different design model than we currently have. In short, how can designers work with scientists to develop new techniques and products whilst remaining cognisant to the impacts these may have? This PhD research is investigating one particular biotechnology, tissue-engineering, and its potential effect on how and what we make, now and in the future.

2.2 Textiles and Tissue Engineering: an introduction

The field of tissue culture[1] was established by pioneering scientists Ross Harrison, Alexis Carrel and Carrel's assistant Montrose Burrows in 1910[2] (Landecker, 2007). Carrel, a surgeon, was keen to develop the field with a view to growing organs outside of the body (Ryan, n.d.). He recognised that tissue culture, and as an extension tissue-engineering, offered a radical way of manipulating our bodies, internally and externally. Indeed, as Hannah Landecker discusses in the introduction to her book 'Culturing Life: How Cells Became Technologies'; Living things may be radically altered in the way they live in space and time and thus may be harnessed to human intention. This history highlights our human relationship to living matter as one structured by the concept of life as a technology.' (Landecker, 2007, p. 1)

Tissue-engineering, part of the field of regenerative medicine, is "an interdisciplinary field that applies the principles of engineering and life sciences toward the development of biological substitutes that restore, maintain, or improve tissue function or a whole organ." (Langer and Vacanti, 1993). There is a triad of critical components for tissue engineering. The first is "a porous matrix or scaffold", second "various cell types", and the third "key biomolecules such as growth factors". (Kun, Chan, and Ramakrishna, 2009, p.289). All of these areas have essential parts to play but "[of] the three key components in tissue engineering, scaffolds is the one that can be manipulated to the greatest extent. A 3D scaffold similar to natural ECM[3] topography is considered to be a critical component for a successful tissue engineering strategy." (Kun, Chan, and Ramakrishna, 2009, p. 290). This replication of the ECM, through the development of different scaffolds, is an area where textiles can be, and are, used as a means of creating successful architectures on which to grow cells. It is this potential which has been explored

[1] "Tissue Culture is the general term for the removal of cells, tissues, or organs from an animal or plant and their subsequent placement into an artificial environment conducive to growth." (Ryan, 2008, p. 1)

[2] Very little changed in the discipline until the 1950s, when the field of tissue culture as it is known today expanded and significantly developed. (Ryan, n.d.)

[3] The extracellular matrix (ECM) is the non-cellular component present within all tissues and organs, and provides not only essential physical scaffolding for the cellular constituents but also initiates crucial biochemical and biomechanical cues that are required for tissue morphogenesis, differentiation and homeostasis. (Frantz, C., Stewart, K., & Weaver, V., 2010)

through the practical experiments carried out in the laboratory at Kings College London (Chapters 4 & 5).

Although textiles have a place in the development of tissue engineering, they have an even more extended history in medicine generally. We have been augmenting and fixing our bodies by replacing parts in imaginative ways for millennia. Some of the earliest surgery recorded (from 600 BC) are reports of the work of Sushruta, widely regarded as the first-ever plastic surgeon, and show his use of textiles and development of specialised tools;

> The Sushruta's contribution in the field of Plastic Surgery can be enumerated as follows:
> [...]
> 6. Use of suture materials of bark, tendon, hair and silk.
> 7. Needles of bronze or bone (circular, two fingerbreadths wide and straight, triangular bodied, three finger - breadths wide)
> [...]
> 9. Fourteen types of bandaging capable of covering almost all the regions of the body and different methods of dressings with various medicaments.
>
> (Saraf and Parihar, n.d.)

From this early use of textiles through to the ancient Mayans replacing missing teeth with Nacre shells (Stevens, 2013), and the first artificially engineered trachea implanted in 2011 (Roberts, 2011), we have been designing innovative ways to repair ourselves with ever-increasing finesse for millennia. Tissue engineering is one of the latest developments towards the goal of being able to fully 'fix' bodies.

All tissue-engineering scaffold designs are developed to mimic the structures found within the body, and textile scaffolds have the potential to provide numerous benefits;

> Firstly, fibrous scaffolds with hierarchical structures can provide a superior surface area for cell attachment, migration, proliferation and differentiation. Secondly, they can also serve as a carrier for biochemical factors to deliver the biochemical factors to the target organs for therapeutic purposes. In addition, these highly porous fibrous scaffolds allow free entrance of vital cell nutrients such as oxygen and cell growth factors, and allow easy diffusion of secreted biomolecules during cell growth.
>
> (Kun, Chan, and Ramakrishna, 2009, p. 291)

Approaches to developing scaffolds for research vary but generally they are either developed in-house by material science departments, or bought through third party suppliers such as www.bio-scaffold.com. There are also numerous constraints on the design of implants, from

biocompatibility of materials used, through to tensile strength requirements. The majority of textile scaffolds are made from polymers (Kun, Chan, and Ramakrishna, 2009, p. 293); however, there is a range of materials used as seen in the table below (Figure 1) alongside the construction techniques for each.

Table 12.1 Various scaffolds used in tissue engineering (Tao, 2001)

Tissue engineered biological substitutes	Examples of scaffold materials*	Scaffold structures: yarn (y), weave (w), braid (b), knit (k), non-woven (n)
Bladder	PGA	Textile (n)
Blood vessel	Polyester(Dacron); PETE; polyurethane; PGA; PTFE; PLA; PLGA (Vicryl), PLLA-CL	Textile (n, w, b, k)
Bone	PGA; PLLA; PLGA + hydroxyapatite; polyethylene	Textile (n), foam
Cartilage	PGA; PLLA; PLGA	Textile (n)
Cornea	Collagen, fibrin, polyester, copolymer of PDMS and PNIPAAM	Foam
Dental	PLA; PLGA (Vicryl)	Textile (n), foam (porous membrane)
Heart valve	PGA	Textile (n, w)
Ligament	Collagen; PETE; polyethylene; PGA; PLGA;	Textile (y, b, n, k), foam
Liver	PGA; PLA; PLGA; polyorthoesters; Polyanhydride; PLGA; viscose rayon	Textile (n), Foam, 3D printed
Nerve	Collagen-glycosaminoglycan; PGA	Textile (n), foam
Skin	PGA, PLGA, nylon, collagen-glycosaminoglycan; chitin/ chitosan, alginates	Textile (n, w, k), foam
Tendon	PGA; PETE; silk	Textile (n, y)

*PLGA: poly(DL-lactide-co-glycolide), PGA: poly(glycolide), PLA: poly(L-lactide), PLLA-CL: poly(L-lactic acid-co-ε-caprolactone), PETE: polyethylene terephthalate, PTFE: polytetrafluoroethylene, PDMS: poly(dimethyl siloxane), PNIPAAM: Poly(*N*-isopropylacrylamide)

Figure 2.1

(Kun, Chan, and Ramakrishna, 2009, p. 299)

Any material chosen for the creation of a scaffold needs not only to be biologically compatible, safe for implantation into the body, but ideally also biodegradable. During the development of the material archive (see chapter 4) a range of different fibres were seeded with cells, many of which have never been trialled before; some may have applications in regenerative medicine, others not. This is down to the fact that you would not be able to implant all of them into the body, but if this technology is used for the creation of new products, then this restriction does not apply - the materials need only be biologically compatible in that they support cell growth.

Alongside the decision as to what material to use, there is also a range of textile techniques that have already been proven as suitable for the creation scaffolds; from knitted blood vessels to woven hernia patches and non-woven heart valve repairs. A review of existing practices using textile techniques showed that the main types of textile structures found in the literature include woven, nonwoven, knitted, digitally embroidered and braided (Karamuk, 2001; Kun, Chan, and Ramakrishna, 2009; Scarlet, Deliu, and Manea, 2010; Akbari et al., 2016). Textiles

are also used for a variety of purposes within regenerative medicine, as seen in the table below (see Figure 2.2).

Textile Type	Organ/tissue	References
single fibers & fiber bundles	ligament	[82, 91]
	tendon	[86, 92]
non-wovens	cartilage	[39, 40, 44, 51, 68, 69, 92-95]
	liver	[42, 51, 96-100]
	muscle	[88, 101]
	bone	[76, 102, 103]
	kidney	[104]
	dental pulp	[105]
	placenta	[106]
	heart valve	[107]
	breast tissue	[52]
weavings	cartilage	[41]
	esophagus	[79]
	skin	[108-112]
	liver	[99, 113, 114]
	bone marrow	[99, 113]
	jaw bone	[115]
	artery	[116]
knittings	cartilage	[41]
	skin	[67, 110, 112]
	urothelium	[117]
	abdominal wall	[86]
	blood vessels	[78]
	muscle	[118]
braidings	tendon	[76, 86]

Table 1.2: Application examples of basic textile structures as scaffolds in tissue engineering of different tissues and organs.

Figure 2.2

(Karamuk, 2001, p. 13)

Of all the different techniques currently in use within regenerative medicine, digital embroidery's ability to mimic natural structures in the body (Figure 2.3), and the reinterpretation of traditional textile skills for use in a cutting-edge discipline, were the starting point of this research. In the early scaffold explorations, in the Department of Tissue Engineering & Biophotonics at Kings College London, digital embroidery was the primary technique used (see chapter 4). However, through the development of the research, it became increasingly evident that much investigation is focused around digital fabrication technologies, from the 3D printing of scaffolds through to the cutting-edge work in 3D bio printing. Other investigations into textile applications in tissue engineering also focus on those capable of being

scaled and easily automated: from digital embroidery to weaving and knitting. As one recent paper described; 'The main obstacle for the use of biotextiles for tissue engineering and regenerative medicine is combining state-of-the-art textile machinery, novel biomaterials, and biological advances to create tissues and organs automatically.' (Akbari et al., 2016, p. 763). Whilst replicable and scalable processes are undoubtedly needed for implementation in industry, using fully automated machines in the development of structures does not allow room for quick iteration or a smooth transition in the construction method. This is where there is room for experimentation, and where textile craft could be beneficial in research. With this in mind, and the spotlight on the automatic and machine-made, an exploration of traditional textile craft techniques offered the most exciting and under-explored area.

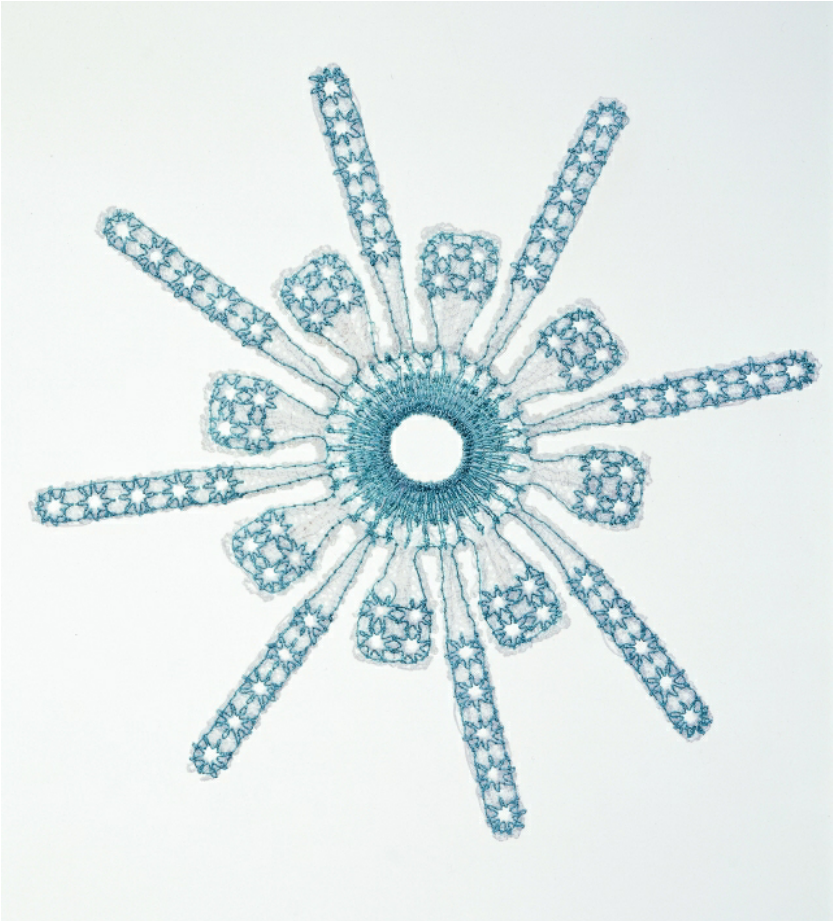


Figure 2.3

Ellis Developments, 'Beautiful Snowflake'
(Ellis Developments, n.d.)

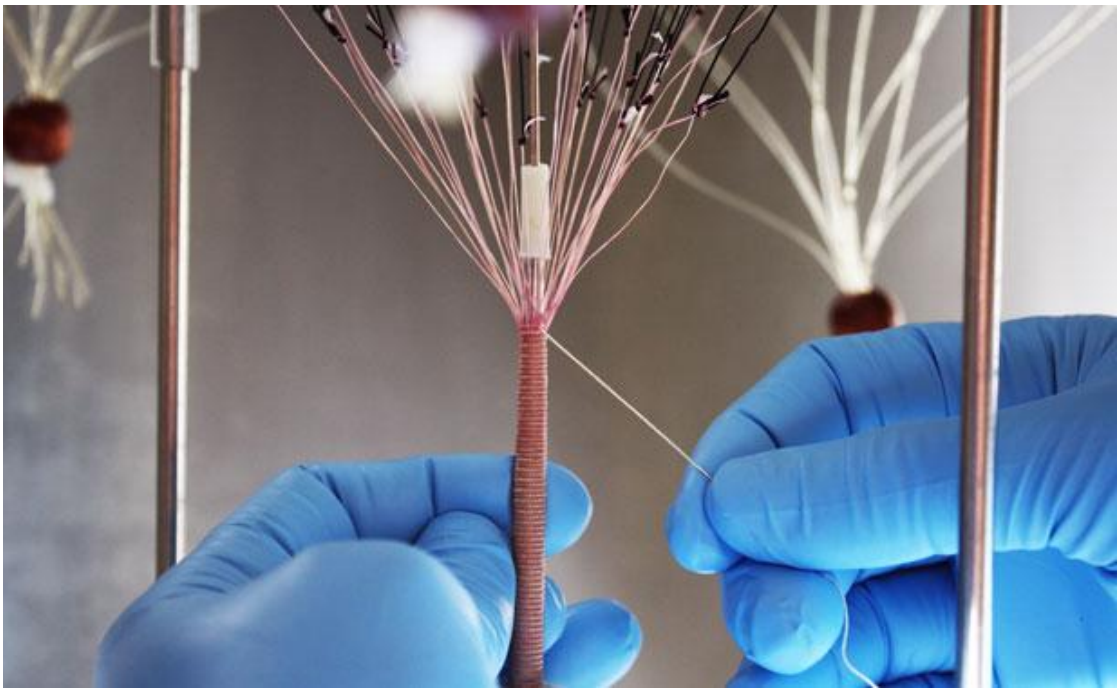


Figure 2.4
Cytograft, ‘Clean Crochet’
(Cytograft, 2012)

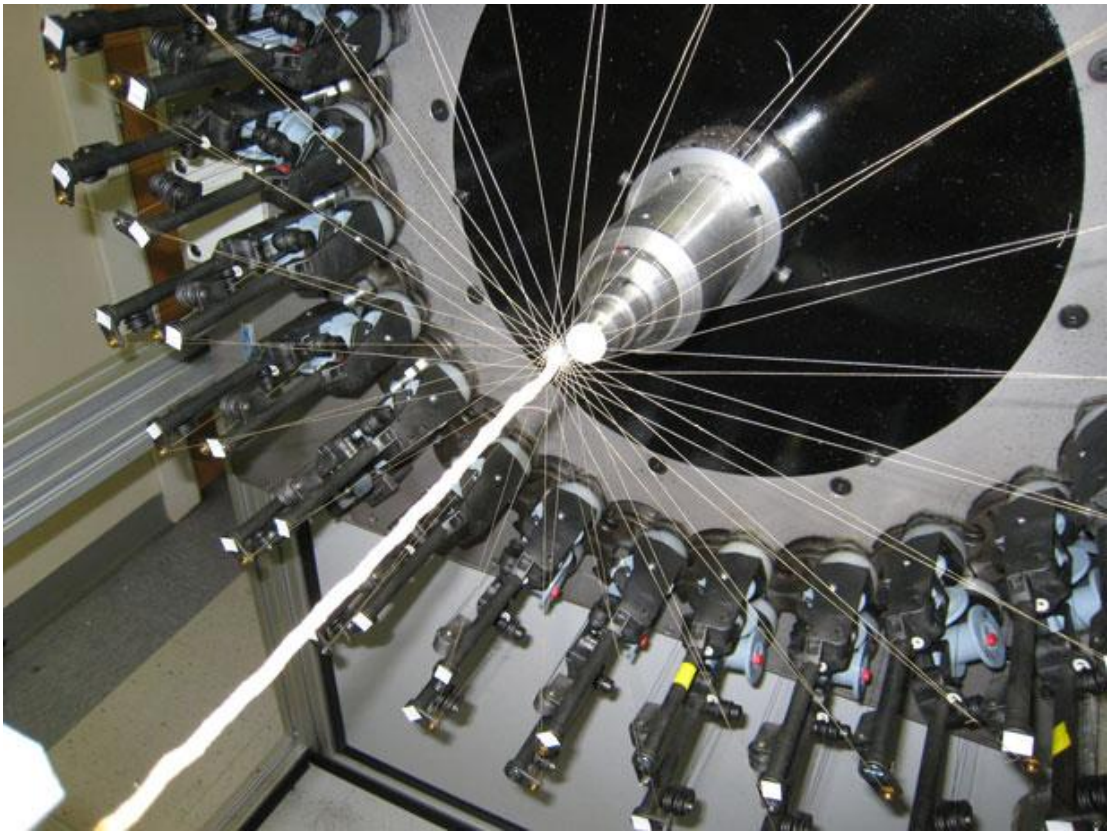


Figure 2.5
Cytograft, ‘Weaving 48 strands of human connective tissue into a tube’
(n.d.)

There are some examples of where traditional textile skills are already being put to use by companies, for example Cytograft (figure 2.4), developed a technique nicknamed ‘clean crochet' (Kurzweil, 2012). The process involves growing sheets of skin, rolling them into ‘skin threads' and working with them in a cleanroom to ‘crochet' (in what appears to be braiding) blood vessels. More recent developments by the company show automation of the process (see figure 2.5), but it appears that craft played a role in honing the technique before it was automated. In an interview about the work of the company, Christopher Breuer[4] talked about the benefits of using textiles; "[creating] textiles is an ancient and powerful technique, and combining it with biomaterials is exciting because it has so much more versatility than the sheet method" (Rojahn, 2012). He went on to say that many of the complex shapes were easier to create using fibres and that "[if] you can make fibers of any length, then there is no limit to the size or shape that you can make." (Rojahn, 2012). All of this points to the potential for craft, and the craftsperson, to play a vital role in the development of tissue engineering technology.

So, whilst it is understandable that in order to bring innovation to the market in regenerative medicine the manufacturing process must be scalable and automated, craft skills offer a way to trial techniques and materials in a quick and iterative way that allows for greater exploration in the earlier research stages. Examples of textile craft skills in use in the laboratory are few and far between, with the two notable exceptions artists: Kira O'Reilly and Whitefeather Hunter. O'Reilly's work ‘Marsysus – Running out of Skin', "explored traditional lace-making techniques interwoven with tissue culturing and engineering to develop an in vitro living lace of skin cultured from cells biopsied from the artist's body." (SymbioticA; Kira O'Reilly, n.d.). Very little else exists online about the project in terms of writing or images (see figure 2.6), but the work was carried out in 2003 as part of a Wellcome Trust funded residency (SymbioticA; Kira O'Reilly, n.d.).

Another, more recent SymbioticA resident, Whitefeather Hunter, worked on a project titled ‘Crafting Biotextiles' and developed a process she coined ‘wet weaving' (see Figure 2.7). ‘In wet weaving, textile materials are stored in fluid and manipulated while soaked. Fibres are immersed in ethanol for a period of hours or days in order to induce and maintain sterility.’ (Hunter, 2015a). As the artist states, she was interested in exploring how "[manually] fostering cell culture growth on traditional, aesthetic textile forms speaks to the intersection of hands-

[4] Christopher Breuer is “a surgeon, scientist, and tissue engineer at the Yale School of Medicine.” (Rojahn, 2012).

on wet biology practices with creative craft processes." (SymbioticA; Whitefeather, n.d.). It is craft practices that have fascinated me since my own residency at SymbioticA in 2011 where I explored seeding skin cells over hand crocheted, and digitally embroidered scaffolds that provided the basis for the techniques archive presented in Chapter 5. Hunter's project also highlights the potential for innovation when textile craft is explored in the laboratory. She has used weaving, crochet and knitting techniques for the production of scaffolds, however, the framing and context of her work is from an art practice and critically based perspective, it appears that the development and analysis of different weave structures have not been the main driver or focus of the work. It is the analysis of how cells orientate themselves around different textile structures, and how this can be guided, that forms the basis of the scaffold development within this practice-based PhD (see Chapters 5 & 6).

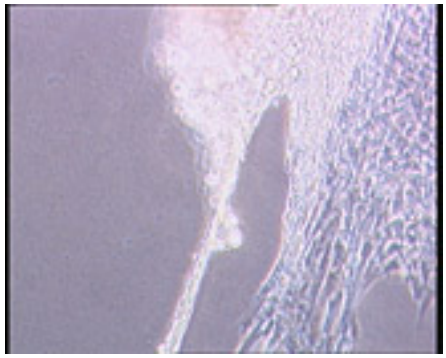


Figure 2.6

Kira O'Reilly , 'Marsysus – Running out of Skin'

Medium: Porcine Primary Fibroblast culture

(SymbioticA; Kira O'Reilly, n.d.)

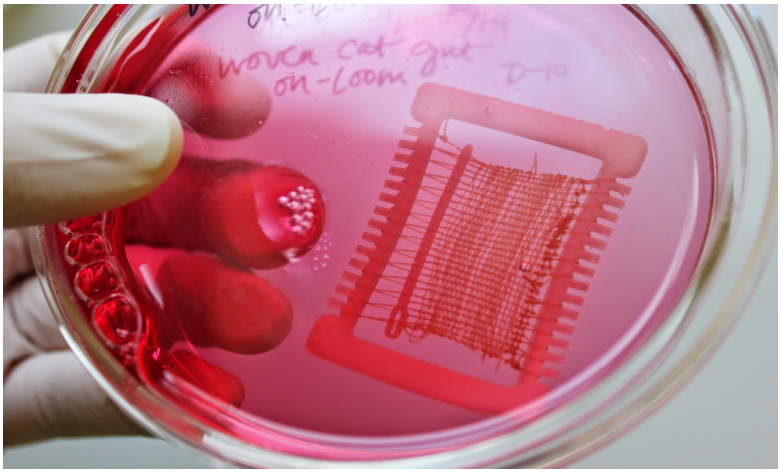


Figure 2.7

WhiteFeather Hunter, 'Woven catgut sutures on 3D printed ABS loom, now enculturated with 3T3 cells. Loom & needle printed at Alternate Anatomies Lab with Stelarc'

(Hunter, 2014b)

The result of bringing someone with textile craft skills into the laboratory is discussed in more depth in later chapters. There are glimpses of this happening in laboratories, for example, the Carr Group's project 'Biopatch' at the University of Oxford involved a hand-loom stationed in the laboratory. "One of the team, Osnat Hakimi, says the loom enabled them to use small quantities of expensive fibre and investigate its properties." (Brimelow, 2014). Although the loom was used to create the support backing for the implant, it is clear that one of the critical benefits of hand craft techniques is their ability to make small quantities in a short time frame. They also allow for easy iteration, something that is harder when working at an industrial scale during the research stages of a project.

Craft's ability to be reactive, iterative and bespoke is vital in this project. The bottom-up nature of craft capabilities allows for an exploration of tissue engineering, exposing where there is room for innovation in the creation of scaffolds. As a science, tissue engineering is multidisciplinary, but there is a real argument to be made for bringing in a broader range of skill sets and knowledge. As argued by Akbari et al. in their paper 'Textile Technologies and Tissue Engineering: A Path Toward Organ Weaving'; "The versatility of textile structures enables tailoring their architecture by controlling the fiber size and orientation, pore size and geometry, pore interconnectivity, total porosity, and surface topography." (Akbari et al., 2016, p.752). However, this paper, as with many others, focused on the mechanical production of textiles. This PhD research intends to make a case for the benefits of opening up research to new approaches. The role of craft is explored further in the next section; which discusses where craft can already be found in the laboratory as well as where it can be used to challenge the status quo and foster innovation.

2.3 Craft and Biotechnology: the hand in the lab

This section of the chapter looks at the notion of the skilled hand in the laboratory and elaborates on how making can be a vital tool for understanding such complicated and radical tissue-engineering technologies. It also argues for the importance of developing new craft techniques to facilitate the designing of future products using tissue-engineering. The speculative nature of the *Biological Atelier* projects (see chapter 3), provided a top-down approach to thinking through what working with living materials in design might mean for fashion. Whereas the next phase of the research looked to engage with the territory from the bottom-up, through first-hand explorations of techniques and tools used for tissue-engineering. With this part of the research, it was vital to get into the laboratory and work with the technology and materials available.

Working in a laboratory requires craft skills, something not ordinarily associated with the practice of science. The word ‘craft' has generally become one loaded with connotations of the amateur or the antiquated. However, Glenn Adamson puts forward a compelling argument, which is that the current view we have of ‘craft' is a construct of the Industrial Revolution – that it was theoretically brought into being as the antithesis to industry and mechanisation. As Adamson argues; ‘In fact I have come to the conclusion that craft in its modern sense was invented as a point of departure, an old thing passing inevitably into history against which new things, industry chiefly, could define themselves. Until that oppositional structure came about there, in a sense, was no craft, at least not in our sense, not in a sense of a defined territory.’ (2012). He goes on to suggest that craft no longer needs, if it ever did, this rigid boundary and that as we move into a post-disciplinary arena, it is the importance of skill that is key (ibid, 2012). It is part of the goal of this research to explore how craft skill, when brought into unfamiliar territories, can produce unexpected and innovative results.

Making has been viewed by theorists, such as Hannah Arendt, as an uncritical process (Sennett, 2008, p. 7). However, this stance, that sets thinking apart as a separate activity from making, something that happens after the fact, is disputed by Richard Sennett in ‘The Craftsman' (2008, p. 7). Peter Dormer, in his book ‘The Culture of Craft' also disagrees with this viewpoint; ‘The separation of craft from art and design is one of the phenomena of the late twentieth-century Western culture. [...] It has led to the separation of ‘having ideas' from ‘making objects'. It has also led to the idea that there exists some sort of mental attribute known as ‘creativity' that precedes or can be divorced from a knowledge of how to make things.’ (1997, p. 18) Heidegger's definition of the word ‘techne' as more than just the skill of the craftsman but ‘also for the arts of the mind’ is of importance here (1977, p. 5). He also stresses the importance of the link between the word ‘techne' and ‘episteme', arguing that "Both words are names for knowing in the widest sense. They mean to be entirely at home in something, to understand and be expert in it." (1977, p. 5) This notion of craft and of making feels most relevant in this research – working with tissue-engineering and textiles to become "expert" in them, to understand them and allow theory to develop through, and from, the making process. "Pierre Bourdieu argues that tacit knowledge and the alternative logic of practice underpins all discovery; and yet the operation of this logic is often overlooked because it is subsumed into the rational logic of discursive accounts of artistic production (Barrett, 2003)." (Barrett, 2010, p. 4). The research's goal within the laboratory is not to allow making to subsume the end result

but to develop a material and techniques archive to sit alongside finished pieces. It is thus celebrating the hand in the lab and its utmost importance in this multidisciplinary field.

The sublimation of tacit knowledge by the theoretical recording of its findings can find its basis in Cartesian ideals. 'The Cartesian division between mind and matter has had a profound effect on Western thought. It has taught us to be aware of ourselves as isolated egos existing "inside" our bodies; it has led us to set a higher value on mental than manual work' (Capra and Luisi, 2014, p. 24). Producing the material and technique archive, mentioned above and explored further in Chapters 5 and 6, was intended to increase the status of the hand, and the handmade, within the laboratory. Creating an archive that celebrates the creation of the scaffold and the process of the science. The influence and basis of the design of the archives was the exhibition 'Manus x Machina; Fashion in the Age of Technology' held at The Metropolitan Museum of Art in 2016 and the accompanying book that was inspired by the Encyclopédie by Denis Diderot and Jean le Rond d'Alembert;

> Published in France between 1751 and 1772, the Encyclopédie was one of the most important, controversial, and provocative publications of the French Enlightenment. Documenting the mechanical arts, it placed métiers, including the trades associated with dressmaking, on the same ethical footing as the arts and sciences, regarded as the noblest forms of scholarly activity since Greek antiquity. Diderot and d'Alembert's elevation of these métiers was an incendiary challenge to established prejudices against manual labor, biases that the authors sought to refute by showing the dexterity, creativity, and complexity involved in the mechanical arts.
>
> (Bolton, 2016, p. 13)

The beautiful plates (see Figure 2.8) in the book show the complexity of craft processes such as embroidery and lace making. Challenging preconceptions around the mechanical arts and their comparison with the sciences formed the basis of recording the tissue-engineered textiles of this thesis. It was of great importance to highlight the multitude of skills, and expertise, involved from both the scientific and craft perspective.

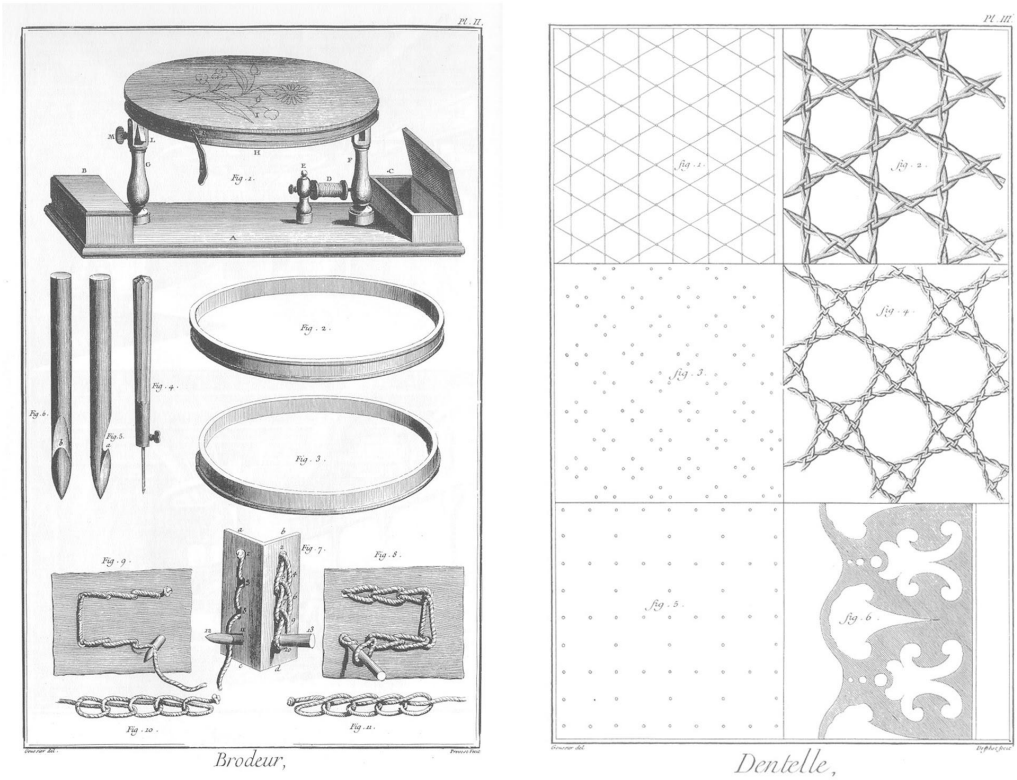


Figure 2.8

Right: ‘Embroiderer’ (Arbor, 2010a)

Left: Lace Making and Stitch Work (Arbor, 2010b)

As a result of tissue engineering's multidisciplinarity, bringing in expertise from biology, engineering, material science and medicine, there is an imaginative quality to the work and, just as Adamson calls for: ‘post-disciplinarity’. I would argue that a tissue-engineering laboratory might be the perfect environment for that work. Paul Carter, in his influential book ‘Material Thinking', writes about the value of interdisciplinary collaboration; ‘In my view, the important work is done at the surfaces between adjacent disciplines.’ (Carter, 2004, p. 178) He goes on to champion the inventiveness of craft and material knowledge;

> Craft is associated with a gift for ambiguity. It is a skill in loosening positions that have been fixed. It naturally disrupts hierarchies of handing-over based on a master-slave relation. It dissipates powerful oppositions, and creates opportunities. But it's also a gift for putting things back together in different ways. Invention and re-membering, following Vico, are two aspects of a single intellectual process.
>
> (Carter, 2004, p. 179)

There is a power in craft's innovative nature, in its ability to re-imagine the potential of materials and processes. There is also value in outsiders coming into a field, such as a textile designer into a tissue-engineering laboratory. Indeed in Kuhn's view, new paradigms can be

brought into fruition by newcomers to a field; ‘Even though prolonged crises are probably reflected in less rigid educational practice, scientific training is not well designed to produce the man who will easily discover a fresh approach. But so long as somebody appears with a new candidate for paradigm – usually a young man or one new to the field – the loss due to rigidity accrues only to the individual.’ (Kuhn, 1962, p. 166) Indeed designers come into laboratories without the ‘baggage' of how things ‘ought to be done'. There is a natural naivety that allows them to ask probing questions, or use a piece of equipment differently, thus challenging the status quo of orthodox scientific training. However, as previously detailed, the discipline of tissue-engineering has much less rigid processes than many other sciences and is by nature inventive. Moreover, its' scientists are not trained to work with materials in the way a textile designer is. Thus there is space for craft in the creation of new approaches in the handling of materials and the production of new types scaffolds. It is at the intersection of disciplines such as textiles and tissue-engineering, where innovative solutions, methods and materialities have the potential to occur.

A further consequence of categorising craft as something oppositional to industry, is that there are many highly skilled makers working with complex technologies that are not represented in history;

> If the nineteenth century account of craft presents it as a static ground, what that means in turn is that any craft that happens within industry must become invisible, or inadmissible, as craft. Which means that you have a big missing storyline in the history of craft because of course artisans were not made obsolete by mass production. [...] With the rise of modern industry skills did not disappear, in fact they became more important than they ever had been before, because it was skilled hands that made the machine tools that would make the goods of Victorian culture.
>
> (Adamson, 2012)

This missing history of skilled workers is also relevant in the laboratory, nowhere more so than in the discipline of tissue-engineering. There is a great deal of tacit knowledge and skill required in the execution of experiments. Furthermore, this is still a process not represented in the literature surrounding science; the result is praised – not the technique that created it. "Inscription devices thus appear to be valued on the basis of the extent to which they facilitate a swift transition from craft work to ideas. The material setting both makes possible the phenomena and is required to be easily forgotten. Without the material environment of the laboratory none of the objects could be said to exist, and yet the material environment very

rarely receives mention." (Latour and Woolgar, 1986, p. 69) It is this inherent culture of paper writing and results' chasing that subsumes science's creative processes.

The process of making craft objects, and the role those objects play, is read as one with dual functionality by Louise Mazanti. Her concept of 'super-objects' has genuine resonance in this research.

> The term super-object serves as a framework to describe the role of craft as a position that draws on both visual art and design discourses while still acting as an independent practice with an independent meaning. A super-object is an object that exists parallel to the object category of the design commodity, at the same time as it contains (super) layers of meaning that relate to visual art.
>
> (Mazanti, 2011, p. 62)

Many of the pieces created through the practice fit this description, especially objects such as the items in the *Haute Bacon* collection (see chapter 3); '[the] jewellery pieces in particular display this duality by embodying layers of meaning surrounding shifting notions of value, skill, craft and materiality, whilst also being designed as products.' (Congdon, 2014a, p. 6) As objects, they have the potential to be worn, but more importantly, demonstrate how working with techniques from the sciences necessitates adaptability in design methodologies. Removing the process from the lab and placing it in a design context facilitated a new set of criteria for the material, one where it was not about the material being fit for use in repairing the body, but instead on how suitable it was for use in products.

The artefacts made through the PhD research are discussed in the following chapters with both their methods of construction and their conceptual drivers unpacked. 'The super-object stands as a metaphor for craft as an independent practice, for a body of objects that grow out of design because they have a form-typological relation to functional objects, even as the objects' artistic (aesthetic or conceptual) concept is central.' (Manzanti, 2011, p. 62). The theory of super-objects presents craft's relationship to material culture as one that functions because the objects created are 'objects of desire of consumer culture' whilst at the same time creating said objects makes real the 'logic that goes behind the established systems of value,' - craft is 'an interpretation of material culture.' (Mazanti, 2010). Craft can occupy a unique position between the art/ life dichotomy, both participating in life as functional, whilst also being 'semi-autonomous objects that comment and reflect upon material culture.' (Mazanti, 2010). This position gives craft a power to be used both practically and to raise questions concerning the

broader implications. For example, textile craft techniques can be used to create a number of architectures on which to seed cells, with the aim of eventually growing products, but it could be argued that those same scaffolds could be read as artefacts that comment on the more extensive implications of working with living materials for the production of consumer goods - the ramifications of which are further explored in the final section of this chapter.

There is power in making things manifest, as the frequently cited physicist Richard Feynman said; "What I cannot create I do not understand". (Schmidt, 2009, p. 81). Schmidt goes on to argue that just because we can create something, it does not constitute full understanding of what has been made (Schmidt, 2009, p. 81). It was a similar sentiment that relocated this research into the laboratory at Kings College London. As a designer and maker, I understand materials and processes through working with them first hand. Throughout this PhD, craft has been invaluable as a method of thinking through concepts, as well as a means to develop new scaffolds and protocols. For me, craft is a process that is nuanced, responsive and iterative, and in many ways much less reductionist than current scientific approaches. Much of the research in the later chapters of this thesis deal with craft and the practical processes involved in working with tissue engineering and its potential to create a new way of growing future products. Craft's ability to also hold a critical perspective is vital, as the materials up for manipulation: living cells, have far-reaching implications as discussed in the final section of this chapter. What is apparent is that the objects in this research indicate a new classification of artefacts in our material cultural history, and it is important to reflect critically on what that means practically, culturally and ethically.

2.4 Living technology: a debate

Throughout the discussion in this chapter, there has been mention of living materials as technologies and as a source of materials. It has covered what role textiles can play in tissue engineering and how craft, as a process, is both practically useful in developing new materials and techniques, as well as possessing the potential to help develop a critical relationship with said new materials and techniques. It is essential, however, to expand further on the idea of living technologies and the wider implications of their design and application. As has been pointed out, this is not a new idea, but one that is gathering increasing momentum;

> In 1890, the biologist Jacques Loeb wrote to physicist Ernst Mach that “the idea is now hovering before me that man himself can act as creator, even in living nature, forming

> it eventually according to his will. Man can at least succeed in a technology of living substance."
>
> (Landecker, 2007, p. 1)

The book 'Living Technology; 5 Questions' explains that '[the] phrase 'living technology' was coined to refer to technology that is alive as well as technology that is useful because it shares the fundamental properties of living systems.' (Bedau et al., 2010, p iii). References to living technology in this PhD are specifically related to the first part of the above definition - technology that is alive, in short technology in the form of cells. This is a radical idea for many, but as is seen from the quote by Jacques Loeb - the idea of living technology was being considered as early as the late 1800s. Indeed, the practice of crafting with living materials is not new - alongside trying to develop new ways to fix our physical forms we have used selective breeding to achieve desired traits, and routinely utilised living materials for our products in processes such as brewing beer or fermenting foods. 'For even longer the use of freshly preserved organisms (wood, leather, ivory etc.) have been part of the human constructed world. Are the kinds of manipulations offered by modern biology so different from the past ones?' (Zurr and Catts, 2003, p. 1). What is newer is using living cells from mammalian sources in order to develop materials and products for commercial applications.

Tissue culture, and by extension tissue engineering, 'as its earliest practitioners observed, almost immediately came to denote both the material thing and the field of knowledge produced by the work with that thing; its history is both a history of ideas and the material things in and through which conceptual change occurred.' (Landecker, 2007, p. 24-5). Taking all that has been discussed in this chapter so far into consideration, it can be argued that biotechnology is where the next paradigm shift in design will originate. Propounding a future where material artefacts are crafted from cells, and products grown to order in the laboratory.

The term 'paradigm shift', originally introduced by philosopher of science Thomas Kuhn, was put forward in counterpoint to the long-held view that science was a steady process of refining theories. What Kuhn suggested was that what actually occurs are extended periods of 'normal science' which are displaced by periods of theoretical upheaval termed 'revolutionary science' (Kuhn, 1962). Capra and Luisi describe periods of revolutionary science as a time "in which not only a scientific theory but also the entire conceptual framework in which it is embedded undergoes radical change. To describe this underlying framework, Kuhn introduced the concept of a scientific 'paradigm', which he described as a constellation of achievements – concepts,

values, techniques, etc. – shared by a scientific community and used by that community to define legitimate problems and solutions. Changes in paradigms, according to Kuhn, occur in discontinuous, revolutionary breaks called ‘paradigm shifts'. (2014, p. 3) Even though the term was developed concerning the history of science, and is disputed by some, it is an apt description of what is happening with the increasing use of biotechnology in design. Just as the Industrial and Information Revolutions altered lifestyles "Now, some predict biotechnology will be the foremost driver of change for the twenty-first century, and synthetic biologists believe that their work will be integral to the success of this envisioned "Biotechnology Revolution" through the intentional design (or redesign) of biology." (Ginsberg et al., 2014) Although specifically referencing synthetic biology, this statement is true of any number of biotechnologies, including tissue-engineering. These technologies have the potential to challenge how, and what, we make across the board. BioMASON are pioneering new methods of manufacturing bricks, using a specific type of soil-dwelling bacteria, which can be made at ambient temperature and are carbon neutral (Biomason.com, 2019). Ecovative are creating mycelium alternatives to Styrofoam packaging that can be composted in 30 days (Seed.com, 2019). And Faber Futures is researching bacteria that secrete pigments which can dye fabrics in the Petri dish using 100 times less water than traditional methods. (Whipple, 2018).

Though the notion of working with living materials for the creation of materials and products is only beginning to be explored practically by designers and material start-ups - the idea of life as a technology has its origins several centuries ago where ‘[during] the sixteenth and seventeenth centuries, the medieval outlook changed radically. The notion of an organic, living and spiritual universe was replaced by that of the world as a machine, and the mechanistic conception of reality became the basis of the modern worldview.’ (Capra & Luisi, 2014, p. 19). Tissue engineering offers even greater mechanisms through which to control living organisms, further developing the Cartesian view of life as a machine to be manipulated at will. The idea of life as a technology surfaces regularly, and many argue that this is nothing really new but simply that the tools now at our disposal, through modern technology, offer more extreme means - that parts of bodies can now live on in Petri dishes and laboratories. What this poses is a threat to ~~is~~ many people's notions of bodies, and the integrity of those bodies, (Landecker, 2007, p. 11). The issue arises because we still lack the cultural language, and understanding, through which to articulate what that means for us as a species. We have not redefined our concepts of what ‘alive' and ‘living' now describe (Catts, 2016). In laboratories, scientists are routinely working with cells as factories, and ‘culturing the living cell outside the body has become increasingly important to making new biotechnical objects.’ (Landecker, 2007, p. 4-5).

Hannah Landecker argues that modern biotechnology views living matter as plastic in nature (2007, p. 10), and perhaps it is this we find challenging to deal with, especially when the possibility of removing it from the realms of medicine into the field of commercial applications. As Suzanne Lee, in the groundbreaking book 'Fashioning the Future', puts it;

> The ethical, ecological and economic arguments surrounding biotechnology are complex, and although its use in medicine has gained a measure of acceptance because of its obvious benefits, manipulating nature for consumer products is likely to meet with more resistance. Will today's life saving medical technology be used to design tomorrow's fashions?
>
> (Lee, 2005, p. 72)

These issues are becoming ever more pertinent as the potential of tissue-engineering is now becoming of interest not just to the scientific community, but to art, design and manufacturing. Already there is some precedent for designers and artists working with living materials, however very few have worked with tissue-engineering due to its specialist nature. The majority of designer engagement with the field (to date) takes the form of speculative projects. They propose future uses for the technology as a way to engage when unable to work hands-on with living matter in a laboratory. For example, Nancy Tilbury's 'Digital Skin's Body Atmospheres' (2010) project (figure 2.9) suggested growing skin dresses and bone stilettos. Veronica Ranner's (2011) 'Biophilia' proposed using silkworms to construct bespoke scaffolds and explored what the development of synthetic skin might mean ethically (figure 2.10). And KnoWear's provocative 2001 'SKINTHETIC' work imagined how fashion brands might utilise tissue-engineering to extend advertising into the skin itself (figure 2.11). Indeed, my own first engagement in this research with tissue engineering was through a speculative design project (see chapter 3). However, one notable exception to designers engaging on a purely speculative level was the innovative 'Biojewellery' project (figure 2.12). This research saw couples design wedding rings that were subsequently grown, within the laboratory, from their partner's bone cells, and finished using traditional jewellery techniques (Thompson, Stott and Kerridge, 2006).

Another groundbreaking example of creative practitioners working with biotechnology is the work of the Tissue Culture & Arts Project (TCA). Interestingly, so far, more artists have worked in laboratories than designers. In part, this can be attributed to SymbioticA – the research centre that was set up by TCA founders Oron Catts and Ionat Zurr. One of the most influential pieces of work created by the TCA project is their 2004 'Victimless Leather Jacket' (figure 2.13) – a small jacket shape grown using immortalised mouse cells. The work intended to 'confront

people with the moral implications of wearing parts of dead animals for protective and aesthetic reasons and will further confront notions of relationships with living systems manipulated or otherwise.' (Tca.uwa.edu.au, n.d.). As is clear from this statement, the position of the TCA project concerning working with living materials is a critical one. Creating a space for criticality and debate is of the utmost importance in a field such as this. It allows for the discussion of our shifting notions of what 'living' means, affording us the opportunity to unpack what it signifies to us culturally and to begin to develop a language around these new ideas. In practical terms the cells that live in laboratories are very much 'less alive' and less organised than any plant for example, and yet at times we seem to want to attach a higher value to them.

> Naturally, when they are parts of a living body the cells are disciplined, they do not wander about where they like, growing actively and reproducing themselves, as the cells in culture do. An organ such as the brain or liver is like the City during working hours, a tissue culture is like Regent's Park on a Bank Holiday, a spectacle of rather futile freedom.
>
> (Wells and Huxley, 1929, p. 29)

Perhaps what this uncovers is our discomfort with attaching ideas of commerce to materials that were once from a human source. 'The creation of commercial products from human tissue has raised questions of profit and property, of consent and control. Participants in a range of legal and social disputes over body parts are asking whether tissue and genes are the essence of an individual and a sacred part of the human inheritance – or whether they are, as a director of Smith-Kline Beecham purportedly claimed, "the currency of the future."' (Andrews, 2001, p. 8). It seems to be that it is the source of the cells, alongside a lack of understanding as to the real capabilities of biotechnology, that is where the most significant amount of unease originates. Indeed, can we extend this idea of cells being a sacred part of a body for animals? If we look at it rationally, as Oron Catts and Ionat Zurr argue, we have been manipulating animals for use in products for centuries - from eating meat to wearing leather.

The ethical and social implications of how we currently manufacture our products, through ~~the~~ processes developed during the industrial revolution, are just as questionable. Many argue that working with living organisms to grow materials and products offers a much more sustainable system - in that when you look at the micro-level of how organisms manufacture, it is something to be emulated;

> At those levels it becomes evident that there is a critical difference between human manufacturing processes that are noisy and energy-intensive, and often generate toxic wastes, and living organisms producing superior materials silently, at room temperature, and without toxic wastes. Plants, animals, and microorganisms produce

> their seemingly miraculous feats with the help of a wide variety of proteins, which until recently have played no role in human technologies.
>
> (Capra & Luisi, 2014, p. 450)

What is very apparent is the need to make sure we develop these technologies with our eyes wide open, continually having informed discussions on the potential drawbacks as well as the benefits. With this in mind, for the the book 'Living Technology; 5 Questions' contributors were asked to respond to the same five questions about their views on living technology. One of the most pertinent questions asked was; 'What do you consider to be the most interesting and important human or societal implications of research and development in living technology?' (Bedau et al., 2010, p. iii). The answer from Norman H. Packard, CEO of ProtoLife Inc. and Director of the European Centre for Living Technology, is one that many people echo;

> Any powerful technology also carries with it danger. Unfortunately, anticipation of all dangers is inherently impossible for living technology, because of its emergent nature. We must, therefore, develop a dynamic approach to coping with issues as they arise, doing our best to anticipate effects at the earliest opportunity. The emergent nature of living technology means it is impossible to predict everything; it does not mean that it is impossible to predict anything.
>
> (Norman, 2010, p. 129)

Philosopher Mark A. Bedau's answer to the question agrees, discussing the potential benefits and dangers as well as obligations that should be attached, arguing that whichever way things go much of this is down to the social responsibility of those involved with the development of the technology (Bedau, 2010, p. 31). Perhaps danger is a strong word, but however we view it, the implications of a technology (in all senses not just ethically) should not be an afterthought.

Other answers to this question include more practical suggestions as to the potential benefits and the social responsibility to explore a technology that offers a potentially radically more sustainable manufacturing model than we currently have. John McCaskill, Professor of Theoretical Biochemistry (at Ca' Foscari University of Venice), believes that '[living] technology is crucial if today's society is to overcome the dislocation between industrial production and deployment. Huge factories consume remote resources, and generate products and waste that impact remote areas. [...] The industrial revolution, based on the consumption of fossil fuels and mass production, has led society into a spiral of mass produced artefacts that destroys individuality and is unsustainable.' (McCaskill, 2010, p. 118). The only designer surveyed, architect Rachel Armstrong, also discussed the benefits ~~and~~ offered by the tools of living technology, arguing that they 'may give rise to interventions that enable us to address some of

the current grand challenges that have evaded resolution using contemporary approaches.' (Armstrong, 2010, p. 18) However, the answer that most struck a chord with this research was from Professor Martin Hanczyc, Principal Investigator at the University of Trento; 'The most important implication, because it is personal as well as societal, is whether or not the meaning of life should be: humans = technology. Aren't we all living technology? The second most important implication, related to the first, is whether we can redefine our relationship with nature in a sympathetic way that reduces pollution, waste and suffering through new technology, whether it is LT or something else.' (Hanczyc, 2010, p. 83). This quote gets to the core of this PhD's research and the question of using living technology in design.

With all the ramifications of manipulating living materials for commercial ends, designers must engage with the implications of working with tissue-engineering, acknowledging that it offers entirely new ways of manufacturing future products. The 'Victimless Leather Jacket' confronts us with the idea that in years to come we could culture leather in the laboratory. This potential is already starting to be explored commercially by companies such as Modern Meadow – a Biotech start-up that, unusually, has a design team in house. The company was formed when tissue-engineering firm Organovo (which shares the same founders) was increasingly being asked, since they could grow human skin could they also grow leather? (Forgacs, 2013) Modern Meadow has subsequently pivoted its technology away from tissue engineering to fermentation in order to be able to scale, and is therefore working with non-animal sources of collagen.

With tissue-engineering, we are faced with a hugely powerful, self-replicating technology. A technology with the potential to grow materials, such as leather and bone, within the laboratory through to, in years to come, growing whole replacement organs for the body. With all this potential comes a responsibility to not just accept developments at face value, but to explore what it means socially and ethically as well as commercially. 'Although much of our detailed research may not depend explicitly on our value system, the larger paradigm within which this research is pursued will never be value-free. As scientists, therefore, we are responsible for our research not only intellectually but also morally.' (Capra and Luisi, 2014, p. 3). I would argue that this statement must now, and should have always been, extended to designers and the objects we put out into the world, be they living or not.

Figure 2.9
Nancy Tilbury, ‘Digital Skins Body Atmospheres’
(Tilbury, n.d.)

Figure 2.10
Veronica Ranner, ‘Biophilia: Surrvival Tissue’
(Ranner, n.d.)

Figure 2.11

Peter Allen & Carla Ross Allen, KnoWear ‘Skinthetic’

(Allen and Allen, 2012)

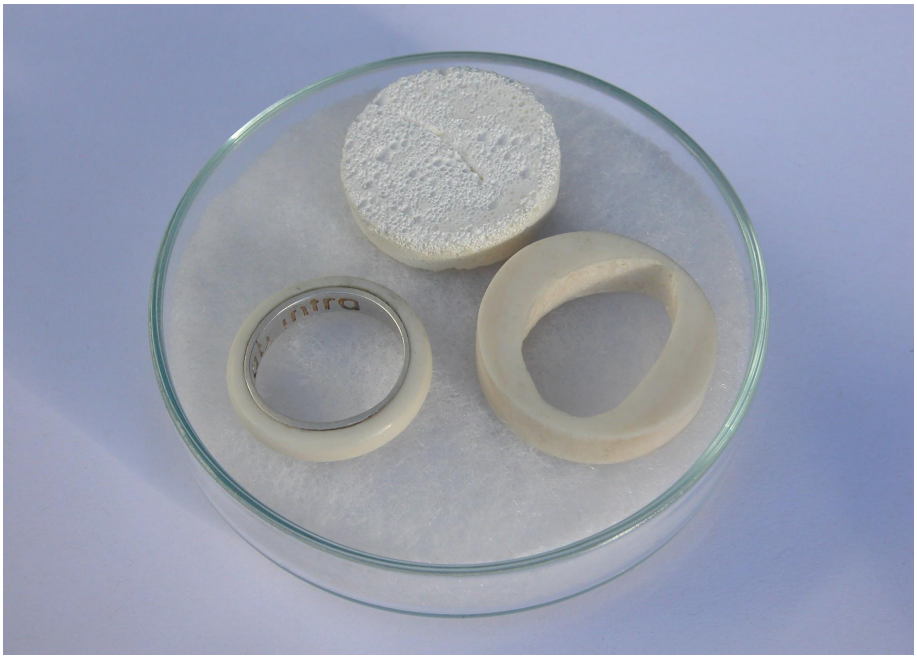


Figure 2.12

Tobie Kerridge, Nikki Stott & Ian Thompson, ‘Biojewellery’

(Thompson, Stott, and Kerridge, n.d.)

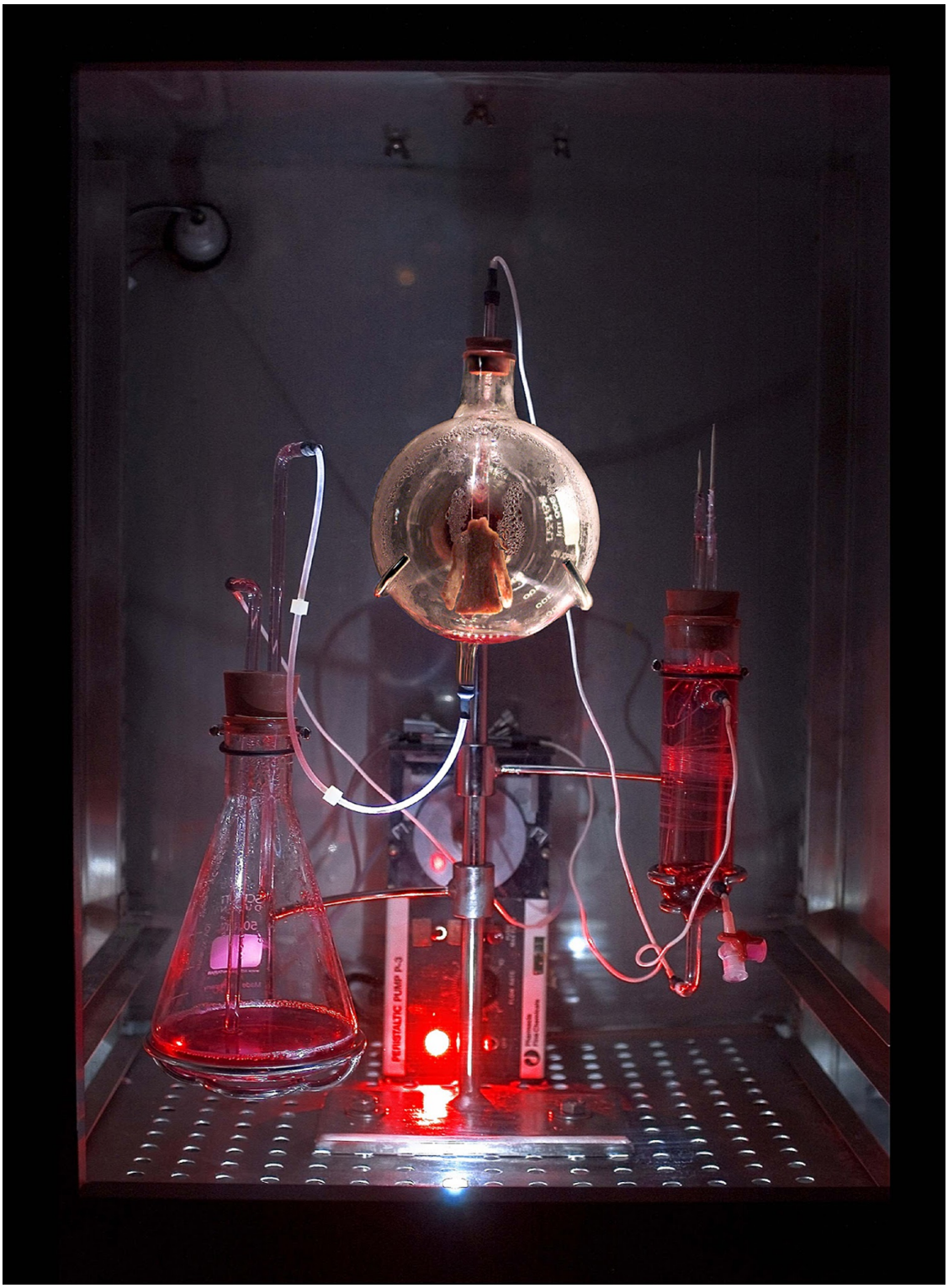


Figure 2.13

Tissue Culture & Art Project (Oron Catts & Ionat Zurr),

‘Victimless Leather- A Prototype of Stitch-less Jacket grown in a Technoscientific "Body"’

Medium: Biodegradable polymer skin and bone cells from human and mouse

Date: 2004

(TCA Project, n.d.)

2.5 Conclusion

This chapter aimed to situate the context for the research, laying out what is currently happening in the field of tissue engineering and regenerative medicine, while outlining what role design and craft can play in its development. Current research in tissue engineering shows real opportunities for innovation from textiles. Whilst this is being explored mainly from an industrial manufacturing perspective, this chapter has presented craft as an alternative/ complementary method of developing scaffolds. Because this project has researched how a range of textile structures can guide the orientation of cell growth, this PhD's research has applications in both regenerative medicine as well as in growing future materials and products. It presents craft skills and knowledge as a dynamic means of exploration and production. Further chapters will explore how textile processes can be utilised to have real impact in the tissue engineering laboratory.

Alongside the outlining of the field of tissue engineering, and craft's potential place within it, this chapter also discussed the implications of biofabricating products using living technology. It unpacked a technology that presents an entirely new set of possibilities for design. The design challenges ahead are twofold; firstly, how do we use design as a reflexive practice in order to engage the public in discussions around the potential opened up by the life sciences?, and secondly, how do we go about the complex task of developing new methods, and ways of making, that take into account such a radically different set of materials?. (Congdon, 2014a, p. 11). The consequences of designing with living materials are further reaching than many of the materials that preceded them. Ultimately the goal of this research is to use design, and craft, as a vehicle to reimagine how, and what, we might make in a future where tissue-engineering offers new materials, manufacturing methods and products. Bringing the chapter to a close is Capra and Luisi's writings, and the beginnings of a discussion on the role and responsibilities of both designers, craftspeople and scientists. Arguing that we must be cognisant of the implications of what we make and put out in the world. The importance of this discussion is such that it interweaves throughout the entirety of this thesis.

CHAPTER 3:
Speculative Tissue Engineering: Biological Atelier - a New Future for Haute Couture

3.1 Introduction

> As biotech and other advanced technologies move out of the laboratory into the marketplace there is a need now, more than ever, to explore the cultural, social and ethical implications of emerging technologies.
>
> (Dunne and Raby, 2008, p. 91)

This chapter introduces the projects that fall broadly under the category of critical practice — covering the work undertaken at the beginning of the PhD, expanding on how this developed the research before the practice relocated itself into the laboratory. This chapter focuses on work carried out in the design studio, firstly centring on the speculative, top-down, *Biological Atelier* projects that shaped the beginning of the research. This section includes the *Biological Atelier Autumn/Winter 2082 'Bio Nouveau' collection* - a series of imagined future couture accessories 'grown' in the laboratory. These are prototypes that seek to open up the possibilities of tissue-engineering to a broader audience, helping contribute to debates around its development and use. Further expanding the future, which the *Bio Nouveau* pieces inhabit, are the *A.C. Skincare Range and the 2082 Atelier Desk*.

This chapter also discusses the methodologies specific to the PhD's speculative design projects. In particular, the importance of image-making, and how this particular design discipline borrows, and references, heavily from popular culture in order to be effective. This 'borrowing' of visual cues and language can also lead to issues in how work is consumed and presented in mainstream media. This then, in turn, asks the question of how responsible are we as designers for the possible futures we present. With this in mind, the chapter discusses the limitations, and merits, of speculative design as an approach to critically engage with the implications of working with living materials. It asks the question: can one be both critical of a technology and embedded within it?

The chapter moves on to look at the potential of expanding the breadth enquiry by using design as a vehicle for debate and education around emerging technologies, whilst also discussing the

issues inherent in this approach. Through covering the areas of practice conducted outside of the laboratory, while still revolving around the central research question, these projects provide a critical interrogation of some of the issues raised. The chapter provides insight into how each project helped develop the research and develop critical thinking, in anticipation of the practice-based research moving into the tissue-engineering laboratory at Kings College London (chapter 4). Overall the chapter explores design, craft, and making as critical and reflexive processes that can help to advance thinking around the use of living materials for future commercial products.

3.2 Speculative Design: designing possible futures

As outlined briefly, in the introduction to this chapter, all the projects covered fall under the broad umbrella of 'critical design practice'. This phrase is used tentatively, and after some thought, due to the fact that descriptors such as 'critical design' have become synonymous with the work of ~~the~~ Anthony Dunne and Fiona Raby and the Design Interactions department at the Royal College of Art (Malpass, 2013, p. 336). This association is in large part because Anthony Dunne introduced the term 'critical design' in the book 'Hertzian Tales: Electronic Products, Aesthetic Experience, and Critical Design' in 1999. As an area of design practice, it has come to symbolise work that is produced outside of the commercial sphere and is synonymous with projects that challenge the status quo and make manifest possible futures.

Design as a discipline often has an uneasy relationship with criticality, with John Thackara once arguing; 'Because product design is thoroughly integrated in capitalist production, it is bereft of an independent critical tradition on which to base an alternative' (Thackara, 1988, p. 21). As a result, design has been working to establish a critical standpoint since the radical design movement of the 1960s and 70s, which is credited as the historical basis for current forms of critical practice (Dunne and Raby, 2013; Malpass, 2013; Rossi, 2013; Mazé and Redström, 2007). Regardless of this precedence, there is still an urgent need, as Matt Malpass argues, to 'legitimise the practice' (2013, p. 335). He goes on to suggest that this 'legitimisation must come about through critique and problematization of the practice itself.' (2013, p. 335). This is because as a discipline, within design, critical practice is still relatively new and is less established theoretically; 'In design research, where ideological bases rule and theoretical grounding is essential as a reference point, critical practice has not been viewed as a serious form of design.' (ibid, 2013, p. 335). However, the materials, products, and situations that designers create are continuing to become ever more complicated. It is an intriguing

proposition for design, in certain circumstances, to be able to divorce itself from its commercial role in order to question the social and cultural implications of what we make and consume.

Although the term 'critical design' was coined by Anthony Dunne in the late 90s, in a more recent book entitled 'Speculative Everything' written in partnership with Fiona Raby, they name their practice 'speculative design'. Dunne and Raby describe speculative design as work that looks 'to create spaces for discussion and debate about alternative ways of being, and to inspire and encourage people's imaginations to flow freely. Design speculations can act as a catalyst for collectively redefining our relationship to reality.' (2013, p. 2). It is important to note that Dunne and Raby argue that speculative design is more of an attitude than a methodology and that many designers partake in the same type of practice but use different names for what they do (2013, p. 34). It is partly for this reason that the terminology around critical practice can be confusing, and requires classification, due to the dominance of the work from the RCA. As Matt Malpass writes; 'In proving its continuing importance, it is essential to examine and understand critical practice not in terms of the arts, but rather in relation to traditional ideas of satire, narrative, and rationality. This conceptualisation challenges the idea that one form of critical practice in design – that is the critique commonly associated with the work of Dunne and Raby at the Royal College of Art in London – is completely representative of contemporary conditions in the entire field.' (2013, p. 336). In response to this Malpass, whose PhD developed a taxonomy for critical practice, defines three types; associative, speculative and critical (2012).

Within this PhD, and in particular the projects discussed in this chapter, Matt Malpass's definition of the three types of critical practice are used to classify the work;

> The first, associative design, emerged from designer-maker traditions and draws on mechanisms of subversion and experimentation in conceptual art. Such practice has been discussed at length by Mazé and Redström (2007), Robach (2005), and Rossi (2013). Alternately, speculative design specifically focuses on science and technology, establishing and projecting scenarios of use; it makes visible what is emerging, reflecting the social anthropologist Paul Rabinow's terms by both slowing down the present and speeding us up to that present's future (Hunt 2011: 44). It has a relationship to science and technology studies (STS) discourses (Kerridge 2009; Michael 2012; Ward and Wilkie 2009; Wilkie 2010). Critical design, however, emerged from developments in the field of human–computer interaction and later interaction design. In that context, it challenged conventional approaches in designing human–object interaction (Agre 1997; Gaver and Dunne 1997; Seago and Dunne 1999; Crampton Smith 1994; Redström 2008; Hällnas and Redström 2002). Each of these practices

> challenges the essentialist view that product design needs to be grounded in need, efficient use and technical function.
>
> (2013, p. 336 - 7)

Following this taxonomy, the *Biological Atelier* projects fall within speculative practice, focusing on the potential of applying tissue-engineering techniques in fashion production, and how these might be utilised in future haute couture. 'Situated between emerging scientific discourse and material culture, speculative design operates in an ambivalent space; it typically focuses on the domestication of up-and-coming ideas in the sciences and applied technology.' (Malpass, 2012, p. 338). However, in contrast, projects in the following chapter such as *DeCellular* and *Haute Bacon* fall under the category of associative design, which in turn has many parallels with Louise Mazanti's 'Super Object' theory. Indeed, this area of critical practice 'emerged from designer-maker traditions and draws on mechanisms of subversion and experimentation in conceptual art.' (ibid, 2013, p. 336).

As discussed briefly in the previous chapter, the majority of speculative design projects that engage with science, and living materials in particular, tend to be theoretical rather than practical in nature. Work in the field 'is characterised by its inquiry into advancing science and technology. It aims to broaden the contexts and applications of work carried out in laboratories and show them in everyday contexts.' (Malpass, 2013, p. 340). That the majority of projects are theoretical and do not attempt to work with scientific techniques or scientists directly, is for several reasons. On the one hand, it can be necessary if the technology in question is not yet capable of what the speculation is proposing. It may also be valuable to suggest a use for a technology before it becomes a possibility, with the aim of questioning if it is something we would want for that technology's trajectory. The second reason may be that it is a conscious decision not to work directly with scientists, and to only employ their expertise as consultants in projects, so that the designer does not feel unduly influenced and unable to explore a potential adverse side of a technology (Dunne and Raby, 2013, p. 54). Fundamental with all speculative design projects is that they are created as design for debate, with the idea that through physically manifesting the potential of a technology it provides opportunity for the public to engage in the discussion around its possible uses and development.

3.3 Biological Atelier Projects

This section covers the speculative design work undertaken at the beginning of the PhD. It expands on how these projects sought to use design as a vehicle for debate, and education,

around emerging technologies potential impact on future materiality and textile practice. *Biological Atelier: 2082* is a collection of speculative design projects 'concerned with exploring what biotechnology will mean for the manufacture of luxury products within the fashion and textiles sector; where new materials are fashioned from cells, not fabrics.' (Congdon, 2014a, p. 2). It sought to do this through the production of design probes[5] that provided a critical top-down view of the potential implications of growing our future haute couture. The series consists of three projects; *Biological Atelier: AW 2082 'Bio Nouveau', Biological Atelier: A.C. Skincare Range* and *Biological Atelier 2082 Desk*.

Design has been described as 'a holistic, interdisciplinary process of discovery and ideation that can address messy, complicated, poorly defined challenges in ways that not only transform products, but the individuals designing them and the customers as well.' (Kressy, 2015). This definition is ultimately the goal of critical practice - to use design as a vehicle to reimagine how, and what, we might make in a future where emerging technologies offer radical new materials and products. The following projects each deal critically with the potential opened up through tissue-engineering. As projects, they expand on the use of critical design practice as a design strategy to explore some of the issues around the use of the technology. The more extended role these projects play in the PhD research is also discussed, as well as how they have moved the practice forward, and what the limitations to this approach have been. Each project looks at how the transference of a technology, traditionally used for medicine, makes for a new range of materials to be explored through design.

As with many designers, my first engagement with tissue-engineering was not within the laboratory itself. It was a speculative investigation in large part due to wanting to move the practice forward and not yet having access to a laboratory. It was also a conscious decision to use a speculative approach initially to work through some of the ideas, and issues, presented by using tissue-engineering to grow future fashion, before relocating the practice. The project, *Biological Atelier: AW 2082* (figures 3.1, 3.2 & 3.3), uses design skills and methodologies to envision a future where fashion is grown, not made, where customers graft living fashion to their bodies for the ultimate display of bespoke luxury. As a project, it was created to develop the story of the *Biological Atelier: SS 2082 'Extinct'* (figures 3.4 & 3.5), which I produced during

5 Design probes are a way of using design skills to visualise possible futures and are used as a means to open up debate into the potential of new technologies. Philips describes the probes produced by its Design Futures division as a method of "testing a possible future – not prescribing one." (Van Heerdan, 2011)

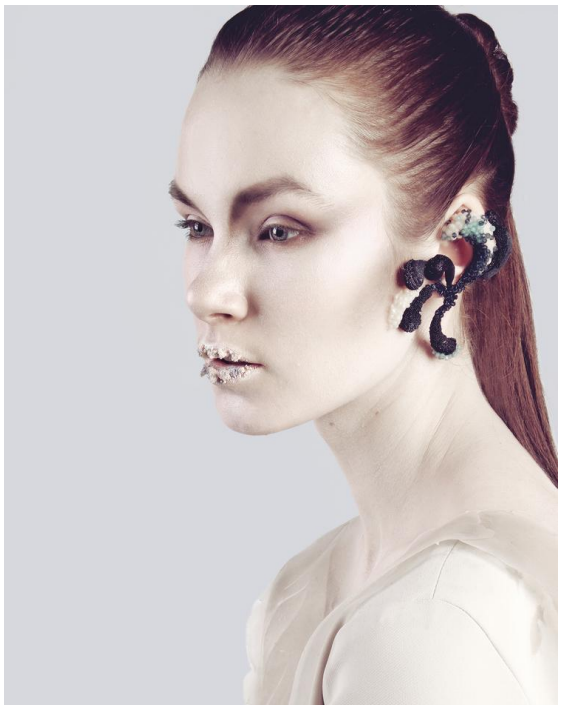
my final master's project while studying on the MA in Textile Futures course at Central Saint Martins, University of the Arts, London. The decision to create a new speculative collection was driven, in part, by a commission to show as part of the 'ALIVE: New Design Frontiers' exhibition, curated by Professor Carole Collet for Espace Fondation EDF. By developing a new series of pieces, some of the ideas that had begun to form in the *SS 2082 collection* were further explored and developed. It also brought up interesting questions, for example, if we were to grow our future couture would we still hold to the traditional Spring/ Summer and Autumn/ Winter fashion schedule?

The pieces from the *Biological Atelier: AW 2082 'Bio Nouveau'* collection come from the imagined couture atelier of 2082. The project imagines, and proposes, a world where materials are grown from scratch in specialist fashion laboratories, and where 'new luxury materials are fashioned from cells, not fabrics.' (Congdon, 2013a). A range of textile trims and accessories was designed, all 'grown' from imagined future laboratory material hybrids. The pieces also played with how couture is worn, suggesting situations where we might look to manipulate our bodies to grow seasonal jewellery, and embellish the skin with precious stones, 'cosmetic surgery has been replaced by tissue-engineered techniques to graft ~~a~~ living, disposable couture pieces.' (Congdon, 2013a)

Figure 3.1

Amy Congdon, 'Biological Atelier, AW 2082: Bio Nouveau Collection'

(Photography by Jesus Madriñán, Dress by Ann-Kristin Abel)

Figures 3.2 (left) & 3.3 (right)

Amy Congdon, 'Biological Atelier, AW 2082: Bio Nouveau Collection'

(Photography by Jesus Madriñán, Dress by Ann-Kristin Abel)


Figures 3.4 (left) & 3.5 (right)

Amy Congdon, Final MA Collection, Biological Atelier, SS 2082: Extinct Collection

(Photography by www.lornajanenewman.com)

The methodology used to develop the projects discussed here was specific to my personal process for creating speculative work. In fact, there is very little in the way of 'official' literature on methodologies used in critical design practice. In a paper, speculative designer James Auger gives the following reason as to why he feels this is the case; 'Every speculative design project is unique and the diversity of possible subjects, contexts, technologies, perspectives and audiences make a definitive 'how to' guide impossible.' (2013, p. 31). One chief process I use each time I approach a project, which looks to deal with possible futures, is scenario planning;

> Scenario planning is about anticipating how the new and the next might impact on the way we live tomorrow. 'Might' is the operative word here: for scenario planning is all about what 'might' happen. Scenario planners, accept that there are many futures, and the best way to anticipate these futures is to envisage all of them in as much detail as possible.
>
> (Raymond, 2010, p. 148)

I find the use of scenario development inherently useful as an exercise in collating information and building a narrative out of that research. Scenario planning is a field of practice from the mid-twentieth century that was used by many, including large corporations such as Shell, to help them make "better strategic choices" (Bentham, 2012, p. 3). However, permutations of the approach have been used extensively in the field of speculative design.

In one of the leading texts in the field (The Economist, 2008) Peter Schwartz describes scenarios as 'a vehicle, as my colleague Napier Collyns says, for an "imaginative leap into the future."' (Schwartz, 1998, p. XIII). In the appendix to his book, Schwartz outlines his eight steps to developing scenarios, for example, 'Step Three: Driving Forces' and 'Step Four: Rank by Importance and Uncertainty' (Schwartz, 1998). Whilst these steps provide a robust methodology for developing scenarios, being specifically designed for businesses looking to future proof themselves, they were used more as a guide in the *Biological Atelier* projects. One of the steps, 'Step One: Identify Focal Issue or Decision', however, is extremely valuable. It suggests that when 'developing scenarios, it's a good idea to begin "from the inside out" rather than "from the outside in." That is, begin with a specific decision or issue, then build out toward the environment.' (Schwartz, 1998, p. 241). The approach of defining a specific issue and researching around it was used in the development of the AW collection. The issue being explored was what will future couture look like, and be made from, when you can grow materials in the tissue-engineering laboratory. This focal point necessitated a top-down approach to both the research and the design[6] of the pieces.

[6] "Begin with the design criteria and create components that meet those criteria." (Autodesk, 2016)

The top-down approach to the project asked the question how and what might we do to grow future fashion, which in turn informed the direction of the research. It looked at existing materials used in couture, such as leather and ivory, and set about researching the technologies that would allow these materials to be produced in new ways. For example asking; 'if we can grow skin in the lab, and thus by extension leather, what are the cutting edge techniques to do so and how could we look to innovate within those processes'? Alternatively; 'how can technologies such as 3D bio inkjet printing be used by designers in new ways'? It also considered how we might invent with these tissue-engineering techniques and processes to develop materials not found in nature. Additionally, it explored what textile skill sets would be needed to develop these materials, extrapolating how techniques like embroidery might play a role - based on the innovations by those such as Ellis Developments and their 'Beautiful Snowflake' (see chapter 2, figure 2.3).

Once all of this research had been synthesised into a scenario, or a possible future as Dunne and Raby would term it (2013, p. 4), the next step was to design objects that could exist in this future - making ideas concrete by materialising them and presenting them to the public. The ultimate goal of the *Biological Atelier* projects was to facilitate debate – exploring how, or indeed if, we should use this type of technology to grow fashion. Through using design skills to visualise how consumers might use these products, it asks people to consider how they might integrate them into their lives. These types of project can be an effective way of facilitating discussion since people understand how these technologies may tangibly impact their lives because what you are discussing is a physical object. The technology in question, tissue engineering, is not without possible controversy as it deals with the materials of life itself and the manipulation of them. Design can play a central role in intelligently opening up tissue engineering's potential, as evidenced in previous projects in the field. One such project that was hugely successful in doing this was 'Biojewellery'. The designers asked participants to donate bone cells and to have these grown into wedding rings for their partner to wear. The reaction to this project often creates diametrically opposed reactions, with some feeling it was a step too far and others asking where they could sign up. It was this type of response I was interested in unpacking - exploring where boundaries lie. For example, testing the idea that it is ok to use tissue-engineering to produce skin for a burn victim, but not use that same technology for the creation of a consumer product.

The *Biological Atelier* collection involved designing a range of jewellery pieces that explored the notion of growing haute couture. This part of the methodology followed a traditional process of design direction development, material sampling, and production of final pieces. The design direction stayed true to the existing practices in fashion where motifs are recycled and reused; in this case, the designs of the pieces were based on paisley patterns. The sampling involved creating a palette of options, the materials used included silicone, microbeads, Swarovski crystals and acetate scales, whilst the techniques included digital and hand embroidery. The main difference was that aesthetically they needed to look as though they could have been grown in a laboratory. The challenge was to make something beautiful that redefined the visual identity of a material that up until now has been presented as something fleshy, provoking instinctively visceral reactions. 'All too often bioart and tissue culture engineering projects end up looking slightly gothic - all test tubes, fluids, and bits of flesh, frequently leaning toward horror. Speculative design projects can provide new forms of visual representation for biotechnology that open up other possibilities for debate, linking the discussion to mass consumerism for instance.' (Dunne and Raby, 2013, p. 61). The driving question was, if something were beautiful enough would consumers care how it was produced, for example, could ivory be acceptable if grown from scratch in the laboratory? As Jeffrey and Shaowen Bardzell argue, the goal of projects following a critical design methodology is to bring about more informed responses from the general public, while also pushing critical thinking within design practice (Bardzell and Bardzell, 2013, p. 2).

In addition to creating design prototypes that were convincing as items that could have been cultured in the laboratory, how these pieces were photographed was also carefully considered. All of the pieces created for the collection were intended to be given context through photography. The creation of an image can be a crucial component in speculative design. Imagery is how many people interact with works of the discipline, and as a medium, it can help further communicate the concepts inherent within the work. In the case of the *Biological Atelier* project, the pieces made were intended to be future haute couture items. This idea could be one that is easily dismissed as science fiction; however, by presenting them in a context that is familiar to many, it helps connect the work to people's lives. In curating the photoshoot for the project, all aspects were carefully selected; from the choice of model and poses to commissioning a dress and make-up design (figures 3.6, 3.7 & 3.8). The creative direction of the shoot and the visual references collated, in creative collaboration with Ann-

Kristin Abel, were taken from editorial fashion imagery. This brief was given to both the photographer and make-up artist in preparation for the shoot.

The intention of presenting the collection of future couture jewellery in this manner was to place them in the context of an editorial feature. For them to appear, at first glance as though they could have been lifted from any current high fashion magazine, they are designed to be close enough to current reality that any viewer can see themselves within it and imagine how it could impact their life. 'Critical Design needs to be closer to the everyday, that's where its power to disturb comes from. Too weird and it will be dismissed as art, too normal and it will be effortlessly assimilated.' (Dunne and Raby, 2007). Leading up to an exhibition showing the *Biological Atelier* work an email was received, by the venue, commenting on the use of 'underweight models' in the photographs and in fashion photography in general. Firstly, it is essential to state that the model used was healthy and in no way underweight. Secondly, this reaction suggested that the imagery was successful in placing the work in the current visual rhetoric of high fashion editorials. In addition to the choice of model, the other two principal elements designed for the shoot were the dress and make-up. The dress was designed, and made, by Ann-Kristin Abel, and it was inspired by the items from the collection - the edges of the garment were cast in silicone to make it look as though it was melding into the body as though it too was grown. Finally, the make-up for the shoot was mostly chosen to be editorial in nature. One particularly carefully developed element was the lip make-up. The idea was to make the model look as though her make-up had been 'grown' onto her lips using bacteria. Various tests were done to achieve the right aesthetic (figure 3.9), and this was used in the final shoot on several images to further add dimension to the future being presented. Imagery can be used as a powerful tool within speculative design to 'construct narrative and create arresting visions of the future' (Ward, 2011). However, inherent in the power of a convincing image, there is also the potential for any image to be used and misinterpreted. If, and how much, designers have a responsibility in this regard is further discussed in the last section of this chapter.

Figure 3.6

Photoshoot moodboard for visual direction and atmosphere, created in collaboration with Ann-Kristin Abel

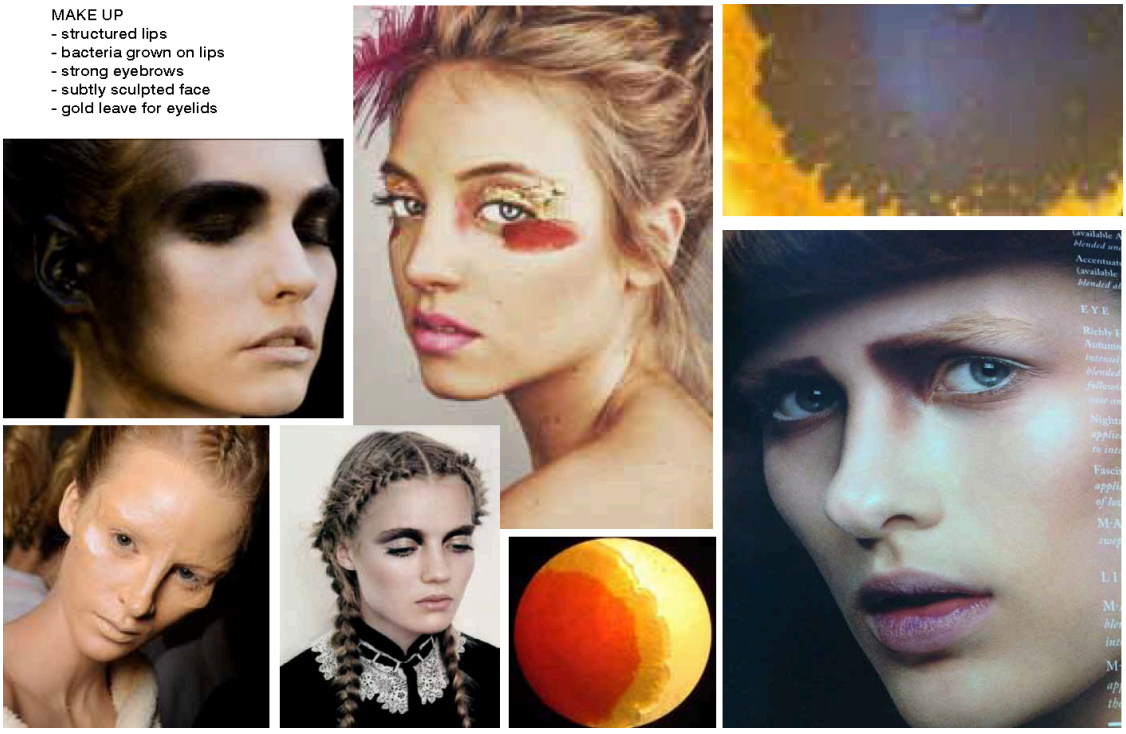


Figure 3.7

Photoshoot moodboard for make-up inspiration, created in collaboration with Ann-Kristin Abel

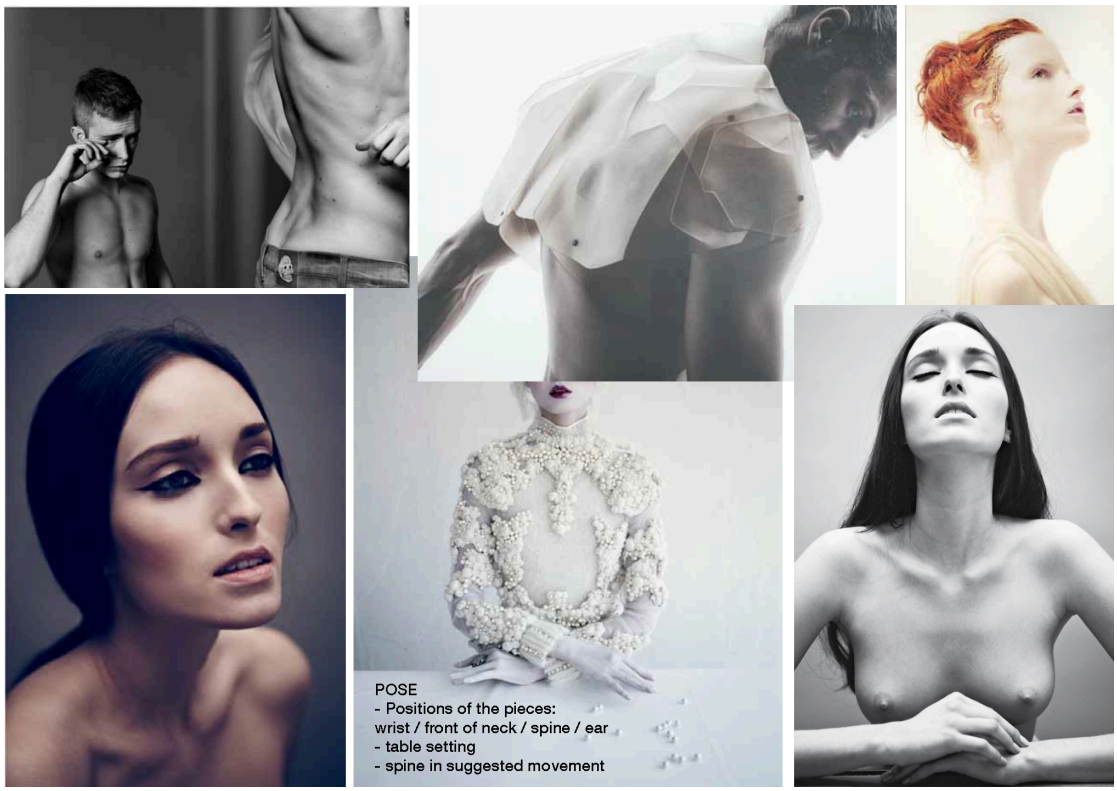


Figure 3.8

Photoshoot moodboard for pose and composition inspiration, created in collaboration with Ann-Kristin Abel

Figure 3.9

'Bacterial lip' test by Kat Vogart

Additional to the main pieces in the *AW 2082 collection* two other companion projects were developed; the *A.C. Skincare Range* (figures 3.10 & 3.11) and the *2082 Atelier Desk* (figures 3.12 & 3.13). These projects were conceived as additions to the 'world' of the *Bio Nouveau* couture collection; they were designed to develop the inherent narratives further. This process of 'world-building' expanded on the future the couture brand inhabited, and fed into the notion that within speculative design projects 'Objects [...] function as a gesture or prop but themselves are often subsumed within larger narratives or contexts, constituting but one part of a larger design device.' (Malpass, 2013, p. 341). For me, this is where the *Biological Atelier* projects were most successful when accompanied by a more extensive 'world' where people could imagine where and how the pieces might be made, or how they might be consumed.

The A.C. Skincare Range (figures 3.10 & 3.11) played with existing norms within the fashion industry where couture houses make a large amount of their revenue from lucrative beauty lines. It suggested, 'a future where beauty products are formulated to be biologically compatible with their users.' (Congdon, 2013b). The products in the range included a '*Graft After Care Solution*', and a '*Graft Moisturiser*', each item in the range is 'specifically designed around the needs of fashioned couture skins.' (Congdon, 2013b). Further pushing the speculation, the styling of the photoshoot for the main AW collection featured a model wearing 'bacterial lipstick' (figure 3.3); if you are going to grow the couture of the future then why not use biotechnology to culture your make-up. All of the above help to further populate the presented future.

As another extension to the *Biological Atelier* world, I produced my vision of the atelier worker's desk of 2082 (figures 3.12 & 3.13) for the Alive exhibition in Paris[7]. 'This fictional atelier presents some of the tools needed to produce jewellery using tissue-engineering techniques.' (Congdon, 2013c) The setup involved a video screen as a desk showing a film of a white-coated atelier worker preparing a scaffold for growth. As an installation, it introduced visitors to the potential future studio where tissue-engineered couture could be produced. 'One way of considering the fictional objects of speculative design is as props for nonexistent films. On encountering the object, the viewer imagines his or her own version of the film world the object belongs to.' (Dunne and Raby, 2013, p. 89) In developing, and staging, the installation visitors to the exhibition were able to envisage their own version of the 2082 atelier they were encountering. By being confronted with tangible objects it made imagining themselves in, and their reactions

[7] ALIVE: NEW DESIGN FRONTIERS, exhibition held at the Espace Fondation EDF, Paris, 26 April – 1 September 2013, (Collet ed., 2013)

to, that future all the more real. By visualising potential futures, people can imagine themselves consuming those products, and in turn, respond to that possibility.


Figures 3.10 (left) & 3.11 (right)

Amy Congdon, A.C. Atelier Skincare Collection


Figures 3.12 (left) & 3.13 (right)

Amy Congdon, Biological Atelier, 2050 Atelier Desk, Alive/ En Vie Exhibition

Figure 3.14

Manchester Centre for Craft & Design, Biological Atelier: The Showroom exhibition

All of the projects under the *Biological Atelier* umbrella were valuable in allowing the conceptual thinking to develop around the use of tissue-engineering for future fashion, and there is an argument to be made that there is real value in removing design from its commercial framework in order to explore its broader implications. The practice of speculative design also allows designers to engage with a technology they may not yet have access to. However, as Matt Malpass argues; 'More and more, the danger is that critical practice becomes overly self-reflective and introverted, sustained, practiced, and exchanged in a closed community.' (2013, p. 334). The *Biological Atelier* projects aimed to present a potential new materiality to the public and to open up a debate. As a process, it allowed the thinking in the research to develop, exploring from a top-down view how fashion production could shift if integrated with tissue-engineering. One of the difficulties it faced in terms of gauging its success was how to successfully create debate around the work, as the only venues where it has been shown are in exhibition settings — added to this how do you capture any debates that do happen? One small example is of an informal exercise carried out when the work was shown in a solo exhibition at the Manchester Centre for Craft and Design. Visitors were asked how they felt about grafting future couture and encouraged to leave a coloured dot as a response (figure 3.14). It is difficult to extrapolate much from exercises such as this, and this is a problem all critical design projects face. How to measure success, if that is important, and how to learn as much as possible from the exercise.

The most successful aspect of the projects from the overarching standpoint of the research was that they helped to facilitate the development of the collaboration with the Tissue Engineering & Biophotonics Department at Kings College London. In that respect, they can be viewed as vehicles that can communicate across the disciplines of design and tissue-engineering. The speculations made on growing future couture helped to aid the beginnings of discussions around what was currently feasible in the laboratory and how textile craft might play a role in bringing it about.

3.4 Speculative Design: problems, promises and reality

'"Falsehood flies, and the Truth comes limping after it," Jonathan Swift once wrote.'

(Meyer, 2018)

The idea of what technology can offer us and whether it is a better model than that which we currently have is an issue that concerned Dunne and Raby when they defined the term 'critical design': 'We coined the term critical design in the mid-nineties when we were researchers in the Computer Related Design Research Studio at the Royal College of Art. It grew out of our concerns with the uncritical drive behind technological process, when technology is always assumed to be good and capable of solving any problem.' (Dunne and Raby, 2013, p. 34). This notion of 'better' is being taken up by designer, artist, writer and previous student of MA Design Interactions, Alexandra Daisy Ginsberg, through the form of a practice-based PhD at the RCA; 'With the assumption of progress comes the dream of 'better': technological progress inevitably looks forwards, focused towards a future state of imagined perfection.' (Ginsberg, 2013). However, technology has no agenda in and of itself; how it is used is the key. As Kevin Kelly puts it in his book 'What Technology Wants', arguing; 'How can technology make a person better? Only in this way: by providing each person with chances.' (2011, p. 348)

How critical practice might affect change, to move beyond merely questioning technology, towards helping shape what is 'better', is one of the main criticisms that has been levelled at the discipline; 'Critical design focuses its attention on even larger things in society than field researchers. Its target of criticism is the way in which design supports consumer culture. Critical designers do not specify who they specifically blame and do not offer an alternative lifestyle.' (Koskinen, et al., 2011, p. 116). Whilst it is essential that we approach the possibilities

of biotechnology, and in particular tissue engineering, with care and consideration, it is interesting to note that nearly all critical projects in the area focus on the potential of the technology rather than critiquing the existing manufacturing model which is already proven to be hugely environmentally damaging.

Added to the issue of how critical projects can help offer some suggestions for moving forward, there is the issue of how they are represented and consumed in mainstream media. Part of what contributes to this issue is the tendency of the media to want 'clickbait' stories, where the information is simplified for an easy read, and misrepresented or inaccurately presented. One example of how press coverage can misinterpret, or misrepresent, a project is the work of MA Material Futures graduate Tina Gorjanc. Her 'Pure Human' masters project suggested a future where the science of 'de-extinction' is used to grow a range of laboratory leather garments and accessories from the skin of (deceased) designer Alexander McQueen using his DNA. Whilst the key conceptual driver of the project aimed 'to address shortcomings concerning the protection of biological information and move the debate forward using current legal structures' (Gorjanc, 2016), the predominant headlines read along the lines of this one by The Daily Mirror newspaper online: 'Fashion student turning Alexander McQueen's skin into leather says she's no "creepy mad genius"' (McCrum, 2016). Many other media sources also wrote as though the project was real, focusing on a sensationalist angle; it was not real - all of the prototypes were made from pig leather. It is important to say here that there were more balanced articles such as those by the design blog Dezeen. However, the main problem remains that the media broadly presented a project with a feasible scientific basis, although a long way off practically in terms of realisation, as a Frankensteinian proposition to be feared. None of the nuance intended by the project made it into the stories that covered it. This is, of course, something that is a danger for all critical projects; you cannot create design for debate but then become upset about what kind of debate you encounter. However, when the issues you are posing to the public are entirely sidestepped, it brings into question if there is a different way to introduce the key points at the heart of a project.

With the above project by Gorjanc as a case in point, the problem remains of how do critical designers present their projects and where? How do you successfully disseminate a project that has vast amounts of research and a solid conceptual grounding? At the moment the venues available are galleries, magazines, and more frequently, online. This poses a problem to this area of design research. The consequences of designing with living materials are arguably

further reaching than many that have preceded them, and it is an important debate to have - with those other than just within the design community. This is also not just a designer's problem to solve; everyone involved, including the media, should take some level of responsibility in how information is disseminated and presented.

The question of how critical design practice is used, and the venue within which it is disseminated, has recently been coming into question. Big brands have been using fictional design and scenarios for many years, but recent reports suggest it's an area of design that is being co-opted and used behind closed doors by brands such as Google (Salmon, 2018). It is important to note here that it is not the fact that companies use design fictions to think through the implications of emerging technologies, it is that these exercises are happening behind closed doors: 'So what happens when speculative design goes corporate? When the practice retreats behind the walls and NDAs of giant Silicon Valley companies, it loses its status as a public provocation and becomes instead something much more troubling. [...]. Foster's video is disturbing, but it's disturbing mainly because it was kept secret, for internal X use only. Google is too big and too powerful to be trusted to build the future of humanity in a top-secret lab.' (Salmon, 2018). The design fiction in question was called 'The Selfish Ledger', and was conceived by Nick Foster who is head of the Alphabet subsidiary 'X' and is also the co-founder of the Near Future Laboratory - a design studio 'that promoted something called "design fiction" at much the same time as Dunne and Raby were thinking about speculative design.' (ibid). The way the project is described uses Dunne and Raby's speculative design language, with the 'reason, surely, is that speculative design is a respected academic discipline with clearly-understood parameters and a not-entirely-friendly attitude towards the technology industry. Design fiction, in contrast, was built on the idea that fact and fiction frequently swap properties and that by designing something fictional and fanciful, you might be laying the groundwork for something entirely real.' (ibid). As with anything that exists at the fringe of a discipline there is always the possibility that it becomes assimilated into the mainstream, co-opted by big business and used in a manner for which it was not intended.

There is a bigger context which cannot be ignored when discussing the interpretation, and representation, of critical design projects in the media - a recent study by MIT found that '[b]y every common metric, falsehood consistently dominates the truth on Twitter, the study finds: "Fake news and false rumors reach more people, penetrate deeper into the social network, and spread much faster than accurate stories."' (Meyer, 2018). One of the reasons these types of stories are so effective is that their content incites strong emotions and therefore gain more

traction with people, and the phenomenon is not just limited to Twitter as a social platform (Meyer, 2018). So with 'fake news' and 'alternative facts' becoming part of the media rhetoric, it is important to understand critical design's impact and role in how the public relates to and understands new technologies. That question could be a PhD in its own right. However, my own approach to this topic is to endeavour to be transparent, and have honest conversations about what the work is, how it was made, and most importantly, what was its intended purpose.

Used well, critical design practice can explore complex issues and unpack the notion that new automatically means better, but conceived and presented poorly, it can misinform its audience and add to the problem, not the solution. This idea of being solution-focused is one that was central to a recent exhibition curated by Paola Antonelli. Entitled 'Broken Nature', the show 'celebrate[s] design's ability to offer powerful insight into the key issues of our age, moving beyond pious deference and inconclusive anxiety. By turning its attention to human existence and persistence, the XXII Triennale will promote the importance of creative practices in surveying our species' bonds with the complex systems in the world, and designing reparations when necessary, through objects, concepts, and new systems.' (Antonelli, 2018). There are still likely to be speculative works in the show, but through framing it in the context of design reparations, it appears to be a call to arms for solutions, rather than just debate for debate's sake. Increasingly as the PhD's research developed, I became more and more interested in moving into working with the technology as it is now and to understand what role design can play in its development. I am not alone in this, as '[t]here is an emerging space filled, primarily, with designers who are hungry to deal with the evolution of these design fictions into design facts.' (Toomey and Kapsali, 2014, p. 5). From the next chapter onwards, it charts the movement of the research from being speculative to a practical exploration of the capabilities of tissue-engineering.

3.5 Conclusion/ Summary

This chapter presented five of the earlier projects produced as part of the PhD practice; *Biological Atelier AW 2082 'Bio Nouveau'* collection, *A.C. Skincare Range*, and the *2082 Atelier Desk*. Each of these projects explored the central research question from a critical perspective, exploring in various guises what role textile design and craft can play in working with living materials for design.

The first selection of projects fall under the classification of speculative design in Matt Malpass's taxonomy. Viewed through this lens, they propose, and critically engage, with a possible future for haute couture. As discussed, despite many common features, a definitive methodology does not exist for critical practice. As a result, the methodology used to develop the primary *AW 2082 collection* was specific to this research. Through taking a top-down/ overview approach, the question asked is; how might we grow future couture by researching current technologies, extrapolating their potential, and proposing a future where fashion houses have their own laboratories growing bespoke materials for their clients. Alongside the methodology of developing pieces for a speculative project, the methodologies of image-making and world-building were also discussed. Each element of the imagery and objects that accompanied the pieces were intended to expand on this world - conceptual props including tissue-engineered-skin moisturisers through to an installation that presented what the future atelier/ laboratory may look like.

The intention behind this first series of projects was to make manifest the research carried out into the potential of tissue-engineering, and to present it as fictitious objects with the aim of better communicating what we may be able to do with these technologies in years to come. Through this visualisation, the goal was to open up this field for debate to a broader audience than those in the design or science fields - if you can imagine yourself consuming a grown piece of couture it better allows you to articulate your feelings towards that possibility. However, as the chapter progressed, it also discussed this approach's limitations, considering how to disseminate projects and conduct a fruitful debate. One of the main criticisms, which strikes a chord in this research, is once you have criticised what then? How can we use criticality to help develop better relationships with technologies and their capabilities?

Overall, the process of developing projects that critically engaged with the potential opened up by tissue-engineering, was influential in moving forward the thinking around the possibilities and potential pitfalls. By moving beyond critically exploring issues, which while important and provide fundamental theoretical groundwork, the main aim of the research has shifted through its development. The core topic explored in the following chapters interrogates practically what textile craft can bring to the contemporary tissue-engineering laboratory. This focus on what is currently possible, and what textiles can bring to its development, is driven by the fact that to truly understand a technology I need to work with it. So while it is crucial to remain

critical in the engagement with any technology, it is also essential for me to begin to work towards what might be a way of using it in a new, and responsible, way for design applications.

CHAPTER 4:
Inside and Outside the Laboratory: Developing a New Discipline

4.1 Introduction

This chapter covers the transition of the research from the purely speculative work of the *Biological Atelier* projects as it moved into working with tissue-engineering technology, both inside and outside the laboratory. The chapter initially focuses on the first material archive of the research, *DeCellular*, and the resulting *Haute Bacon* jewellery collection. The *DeCellular* project takes the form of a material archive of decellularized tissue. This process, typically used in regenerative medicine research, was utilised to create a new range of materials for design applications. Following on from the archive, the *Haute Bacon* project uses textile techniques, as well as the materials developed in the previous project, to craft a bespoke collection of jewellery pieces. Both projects take a bottom-up approach to experimenting with an existing tissue engineering technique in the design studio. Exploring craft's capacity for criticality, how the artefacts it creates have a relationship to both design in how they are 'designed' as pieces, and the conceptual nature of art in that they embody deeper layers of meaning (Mazanti, 2011). The material archive, and subsequent jewellery collection, both use design methodologies to create tangible outcomes, whilst at the same time creating pieces that conceptually challenge material values - embodying how design and science practice can merge to offer a new design paradigm.

Following on from the *DeCellular* and *Haute Bacon* projects, the chapter moves to a discussion of the ethical dimensions of the PhD research in the laboratory. The section encompasses the practicalities of gaining ethical clearance to work with living cells for research purposes, before examining the more conceptual/ overarching implications the work tackles. This section is by no means intended to cover all the ethical intricacies and implications of such sophisticated new technology, such an undertaking on its own would amount to a PhD. The topics the research does touch upon, include the use and commodification of human tissue in a commercial setting. Finally, this part of the chapter debates the effect of the engineering mindset when applied to technologies such as tissue-engineering and compares it to more holistic systems thinking.

The last part of this chapter details the first set of experiments carried out in the Tissue Engineering & Biophotonics department at Kings College London, under the guidance of Professor Lucy Di Silvio. The initial research involved the design and creation of scaffolds using digital embroidery technology using predominantly silk suture threads. These scaffolds underwent a series of revisions, as did the design of the experiments themselves. What defined this section of the practice was trial and error, in how to conduct experiments, record them, and understand what should be the next steps. Overall these experiments provided insight, through hands-on engagement, into where the opportunities for innovation exist when looking to incorporate textile processes and techniques into the tissue-engineering laboratory.

4.2 Inverted Skill Sets: tissue-engineering in the design studio

In a step away from the conceptual prototypes developed in the *Biological Atelier* series, the projects covered in this first half of the chapter are *DeCellular*, the first material archive of the PhD, and the resulting *Haute Bacon* jewellery collection. The projects developed out of conversations with biologist turned artist J.J. Hastings, asking 'what if we used tissue-engineering techniques to create materials and products?', and sought to explore the research's central question from outside of the laboratory. In contrast to the *Biological Atelier* series, that engaged with the possibilities of using biotechnology to create future products, these projects took an existing tissue-engineering technique and developed it within the design studio. They were a bottom-up approach to understand and utilise a scientific process in a new way.

The tissue-engineering process in question was 'decellularization', a technique currently used in regenerative medicine research. It involves stripping an organ, e.g. a heart, of its cells, to leave only the extracellular matrix. This matrix constitutes the architecture of an organ and comprises materials such as collagen and elastin. The ultimate goal of this research is to be able to take this structure and reseed it with a patient's cells creating an organ with a reduced chance of rejection.[8] *DeCellular* was a materials research project that took the process of decellularization out of the lab and investigated it as a way to create new materials for use in design. The project was a collaboration between J.J. Hastings and myself, with her role being

[8] Currently this research is still in its experimental stages and there is currently an 80% success rate of re-seeding with cells.

to design a custom bioreactor for the process, and mine being to develop a material archive (see figures 4.1 & 4.2).

For the purposes of developing the archive, I mainly decellularized bacon, using it for practical reasons as its thinness meant removing its cells was less technically challenging, while its size was suitable for trialling numerous different techniques. The process used to decellularize the meat was an immersion protocol using a solution of SDS (Sodium Dodecyl Sulfate), a detergent found in many household products. The pieces of decellularized meat were then treated using various different techniques, including tanning, salt curing, dyeing, and screen-printing. The archive created captures this information in the form of material boards (figures 4.1 & 4.2), presenting a bottom-up approach to working with an existing tissue-engineering technique for design applications. In cataloguing the experiments, new materiality developed, 'highlighting a potential future where our material landscape is very different to how it stands today.' (Congdon, 2014b, p. 6). Alongside this emerging materiality, the project presented 'the unexpected results that occur when techniques from one discipline are explored within another.' (Congdon, 2014b, p. 6) The material samples created through the process of decellularization proved difficult in themselves to classify. The technique is characteristically used in regenerative medicine research to remove all biological information from the tissue. With the very nature of the decellularization process stripping the bacon of its cells, at what point is the material still to be classified as 'animal'? One of the side benefits of working with tissues from the food system is that the meat in question can be past its sell-by date, meaning the process could potentially utilise a waste stream. However, the main aim of these projects is to explore how scientific techniques can be put to new uses, raising the questioning of what other techniques could be repurposed for use in design.

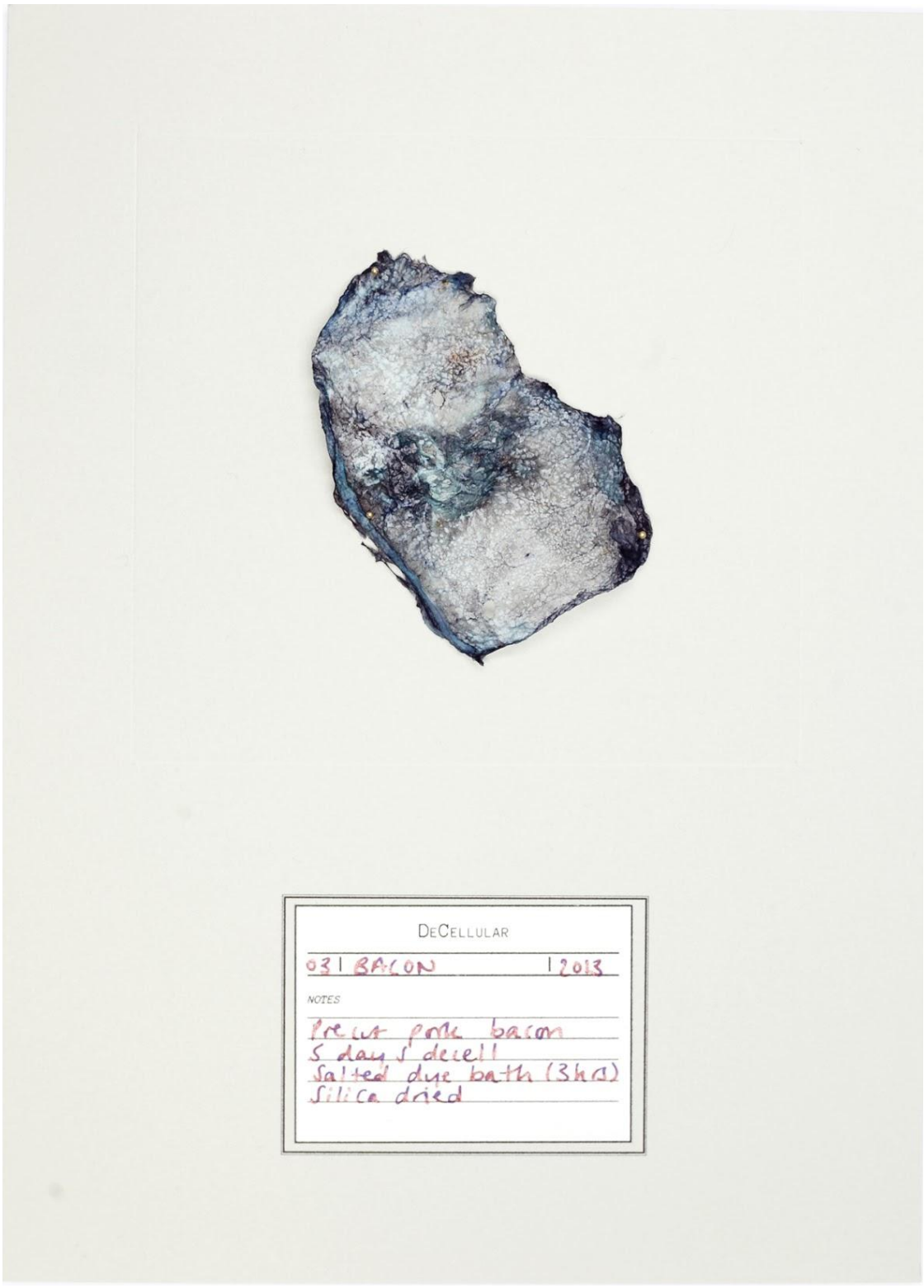


Figure 4.1

'DeCellular' material archive sample (Photography by J.J. Hastings)

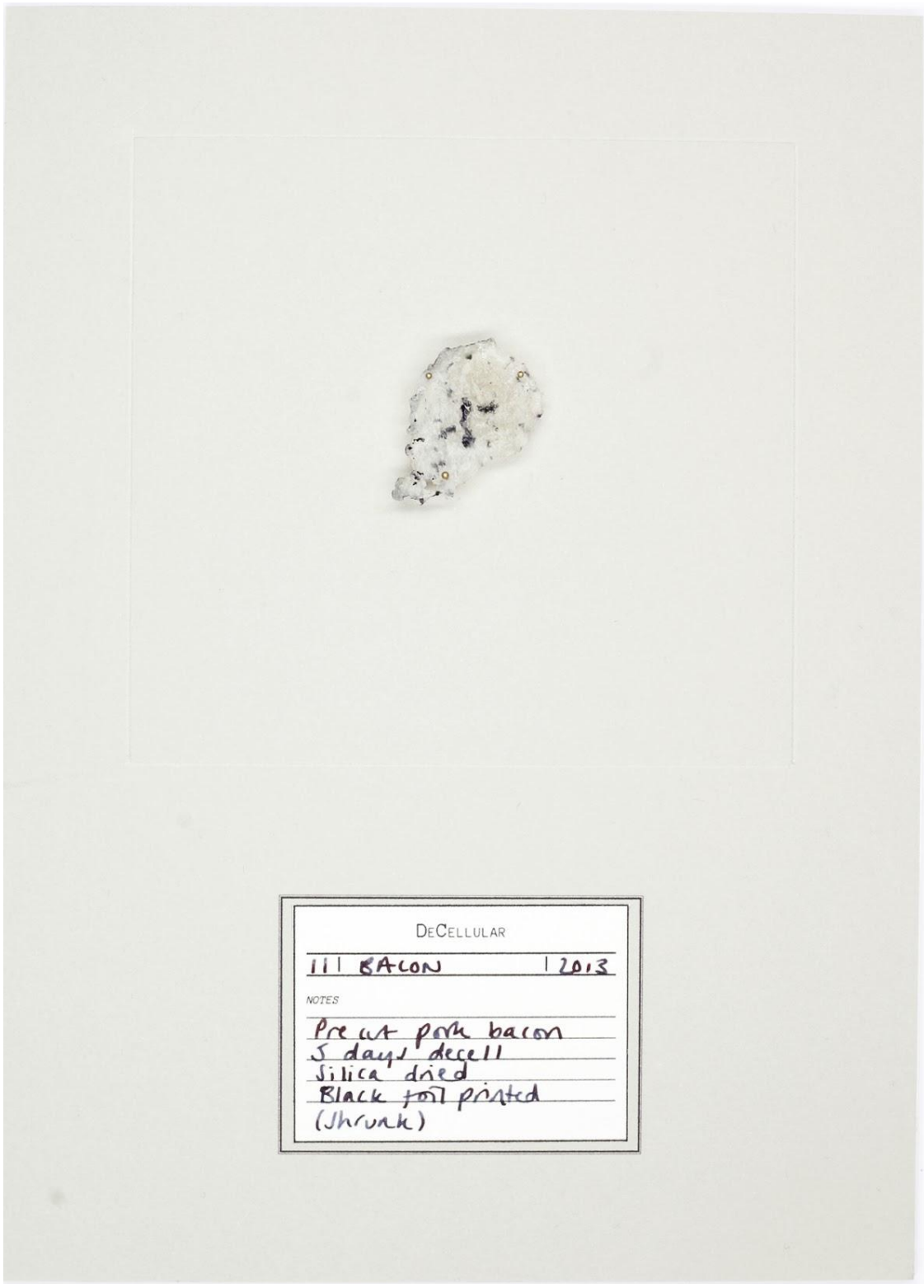


Figure 4.2

'DeCellular' material archive sample (Photography by J.J. Hastings)

As with the stance taken by *Biological Atelier*, both projects discussed in this section also fall into the classification of 'critical practice'. They were not developed within a commercial framework, although their starting points were markedly different from that of the previous collection. In contrast to the speculative design top-down nature of *Biological Atelier* pieces - they fit under the umbrella of 'associative design', as defined by Matt Malpass;

> Primarily focusing on disciplinary content, associative design subverts expectations of the ordinary and the everyday. With an embedded narrative, objects of associative design act as a critical medium, playfully reflecting on cultural meaning while visualizing issues pertinent to design practice today. It is a laconic form of design practice, leaning toward artistic speculation rather than design for production. The aim of this approach presents means for both designers and users to rethink dominant traditions and values in designed objects and their environment.
>
> (2013, p. 337)

This approach to experimenting with a new technique and material is typical of associative design; 'In associative design, designers employ a straightforward attitude to materials, an inventive approach to fabrication processes and methods, and typically a resistance to product styling.' (ibid, 2013, p. 338). This description also resonates with how craft practices are used in the research and the inventive nature of its approach to method and materials. Approaching the exploration of this process in an 'inventive' way led to experimentation with existing jewellery typologies in the *Haute Bacon* collection. The name of which is a playful riff in direct reference to haute couture and the traditional couture atelier.

As discussed above, following on from the creation of the *DeCellular* archive, I wanted to explore ideas of luxury by utilising the materials palette created to produce a jewellery collection that used decellularized meat in its manufacture. The Haute Bacon collection consists of a necklace, bracelet and ear-cuff made from decellularized back and streaky bacon, freshwater pearls, silk thread and cast bone powder (figures 4.3, 4.4 & 4.5). The bacon itself was dyed, woven, macraméd and embroidered in different sections of the jewellery, achieving a highly crafted collection. The main driver behind creating jewellery was to see if it was possible to take a technique commonly associated with science and repurpose it for the creation of a 'luxury' object.


Figures 4.3 (left) & 4.4 (right)

Amy Congdon, ‘Haute Bacon’ jewellery collection (Photography by J.J. Hastings)

Figure 4.5

Amy Congdon, ‘Haute Bacon’ jewellery collection (Photography by J.J. Hastings)

The jewellery pieces for *Haute Bacon* were developed as prototypes, much would need to be done to make them suitable for wear, and as a result, they sit somewhere between the category of product and critical artefact. The pieces have relevance both to craft and making, as well as being objects that embody the research's question.

> Based on our experience, there appears to be inherent power in materializing or "thingifying" one's ideas, sketches, and thought experiments into dynamic artefacts, whether or not these turn out to be products, services, or spaces; and communicate

> these not only to academic groups and industry, but also to use whatever channels are available to become a voice in societal discussions and thus in shaping the future.
>
> (Fallman, 2008, p. 17)

As artefacts, the pieces resonate with Louise Mazanti's concept of the 'super-object', with the material archive boards and jewellery collection embodying both the research question and process involved in their creation;

> The super-object stands as a metaphor for craft as an independant practice, for a body of objects that grow out of design because they have a form-typological relation to functional objects, even as the objects' artistic (aesthetic or conceptual) content is central."
>
> (Mazanti, 2011, p. 62)

In making the jewellery collection, I approached the crafting of the objects as I would when working with any new material - exploiting its strengths and exploring its inherent aesthetics. In this regard, the development of the pieces follows a design methodology, while also needing to be adaptive necessitating that traditional methodologies allow the inclusion of scientific practices. The conceptual ideas behind their creation and the materials used mean there is a duality in the pieces. They have '(super)-layers of meaning' (Mazanti, 2011, p. 62) that embody shifting notions of 'value, skill, craft and materiality' (Congdon, 2014b, p. 6). As pieces of jewellery, they can be worn. However the main driver behind their production was to not to make design commodities but to demonstrate how removing a process from its original setting, and purpose, necessitates a new set of criteria for the materials involved. Criteria where they do not need to be fit for use inside the human body, but instead have a new set of requirements for use in consumer products on the human body.

In contrast to the top-down nature of the *Biological Atelier* project's speculative design approach, where the issue was defined and then the most suitable technologies and processes were researched, the *DeCellular* archive and the *Haute Bacon* collection took a bottom-up approach. The process of decellularization was explored allowing the results to dictate how to use the material. This craft-based approach to the material development and subsequent collection exposed the process behind the end result, with the archive, in particular, showcasing how things were made. There is an argument to be put forward that we have in fact become divorced from how we make things, and as Catherine Rossi points out, there is a tradition, which dates back to the radical designers of the 1960s and 70s, where design turns to handmade modes of production to counter the alienation created by mass-produced products (Rossi,

2015, p. 71). Undertakings such as 'The Toaster Project' by Thomas Thwaites, are examples of designers using craft processes to 'comment on a world in which we do not know how the products that we surround ourselves are made, an opaqueness exacerbated by the increasingly complex and miniaturized nature of the technologies they contain.' (Rossi, 2015, p. 70). Speculative design can be used to provoke potentialities; what are these emerging technologies capable of and what do they mean for the future? Whereas craft-based approaches help to explore, in a much more immediate way, what working with these technologies means for materials and products.

The starting point for this PhD research was the re-appropriation of textile techniques into the realm of tissue engineering. Rather than speculating on what that might mean for the future of fashion, the *DeCellular* and *Haute Bacon* took a different approach, appropriating tissue-engineering techniques for use in textile design now. The projects brought about a blurring of the boundaries between disciplines; adding further potency to the argument that a future designer's training might need to include some rudimentary laboratory skills alongside more traditional manufacturing techniques. Clearly, there are already opportunities for designers to reimagine production methods and materials by utilising scientific protocols within their studios. This was the real value in these decellularisation projects. The development of the material archive in the *DeCellular* project allowed my practice, and thinking, to move forward. *Haute Bacon* embodied the importance of the research, communicating the value in appropriating techniques from different disciplines. Both of the projects went some way to investigating the central question of whether the integration of techniques develops new materiality and informs design, creating a bridge between the speculative work and the laboratory experiments. As pieces, they function as 'super-objects', where they exist as both designed objects, while also embodying a conceptual questioning of material value and the latent promises in technologies such as tissue-engineering to offer us new ways of creating said materials.

4.3 Ethical implications - self-replicating samples

Whilst the ethical implications of the work are discussed briefly in other sections of this thesis it is essential to address it separately as an overarching issue. Since the main aim of the PhD was not to be a research project on ethics, this section will naturally fall somewhat short, purely for the reason there is not the space to be able to cover all aspects. This is also coupled with the fact that as the technology is developing at such a rapid pace it is increasingly difficult to

grasp what all the emerging capabilities ares and their respective concerns. What it will strive to cover are the practicalities of ethics when working in an academic research capacity, moving on to explore some of the ethical questions and issues that are most pertinent to the work as it developed.

Within this research there have loosely been two ‘types' of ethical considerations; the first is that of ‘practical' ethics, i.e. what it means to undertake research with living cells in an academic setting, for example gaining approval through the University's relevant committees. This process dominated much of the early stages of the research from the Central Saint Martin's side. Each starting PhD candidate must submit a research ethics form to be approved. This form is designed to cater for most projects, and the University's guidelines do cover the potential use of human tissue;

> If the research involves any of the following elements then the research is likely to have an ethical dimension for which approval must be obtained […]
> - The use of human tissue (defined in 5.4 below)
>
> 5.4 **Human tissue** is defined as material that has come from a human body and consists of, or includes, human cells. Consent is the fundamental principle of the legislation regarding the use of human tissue: the Human Tissue Act 2004 lists the purposes for which consent is required. (UAL, 2013/14)

The University (Central Saint Martins) guidelines stipulate a need for ethical consent for the use of certain types of human tissue. However, due to the understandable fact that not many students work with human tissue, the standard ethics form provided is not designed to accommodate this and thus necessitated an additional comment at the end of the form (to see the ethics form in full, please refer to appendix 6). In contrast, as a university with a long scientific history, Kings College London has an embedded culture of ethics involving the use of human tissue due to the work that they routinely carry out. None of the work done in the laboratory in the course of the research has required ethical clearance. All of the cells that have been used in the research have all been anonymised commercial cell lines, meaning on a ‘practical' ethics front there have been no issues or prerequisites demanding consent. This is because one of the main rules laid out by the Human Tissue Act is that you do not need to apply for ethical clearance if the source of the cells you are working with, e.g. who the donor was, is anonymous.

As with many PhDs, the research question went through various revisions as the practice advanced and became more focused. The first incarnation was; ‘How can the integration of textile practice and tissue engineering enable us to critically engage with the implications of what it means to work with living materials in design?' The word of most importance in this question was 'critically' as it reflected the direction of the original research, which was primarily looking at the biological integration of fashion and the body. As the research moved away from the more conceptual standpoint of the *Biological Atelier* projects, it became much more focused on the current possibilities of growing materials in the laboratory - exploring what value a textile approach could bring to the development of tissue-engineering. As a result, ethics became a smaller component of the research remit, and its ethical considerations shifted from those specifically focused on the commodification of the body to those of what it means to work with living materials more generally - be that human, mammalian or otherwise. This shift is reflected in the PhD's ultimate question of; ‘Can the integration of textile craft with tissue-engineering techniques lead to the development of a new materiality for future design applications?'

The second set of issues, those I have tentatively called ‘philosophical ethics', are much more complicated. While work may not require consent or clearance under the Human Tissues Act; it still is important to remember that it potentially involves working with human cell lines. There is an almost inevitable abstraction that happens when working with cells, especially at such a small scale, where the material is in such a radically altered state from its source. These cell lines can be bought on the internet (through a laboratory) in the same way that you are able to purchase any other type of material. This very commodification of cells is one of the most challenging aspects for much of biotechnological research;

> The creation of commercial products from human tissue has raised questions of profit and property, of consent and control. Participants in a range of legal and social disputes over body parts are asking whether tissue and genes are the essence of an individual and a sacred part of the human inheritance – or whether they are, as a director of Smith-Kline Beecham purportedly claimed, "the currency of the future."
>
> (Andrews, 2001, p. 8)

It is phrases that liken cells to currency that cause discomfort; ‘the commodification of human cells, tissues and organs incites particular concern because boundaries usually assumed to be natural and inviolable are inevitably transgressed, raising concerns about ‘self' and ‘other', ‘identity', ‘genealogies', group continuity and so on.’ (Lock, 2002, p. 65). It is the way in which the materiality of our bodies is now up for sale, and use, in a way it has never previously been; ‘There is an apparent disconnect between how the human tissue is treated by the science of

biotechnology, as a resource and commodity, in comparison to our social relationship with the body' (Andrews, 2001, p. 173). 'With interesting human genes the price can reach the billions seen as a case in point (Andrews, 2001, p. 25).' (Congdon, 2014b, p. 3). This value has been achieved previously by certain genes being patented and having successful treatments developed off the back of the research. Yet, however unsettling these ideas might be, there is an argument to be made that we have been trading, altering, and transgressing the boundaries of the body for centuries. The questions to ask are; is the potential offered up by modern biotechnology really that different, and would it be more acceptable to us if it were animal as opposed to human cell lines?

As the PhD's work in the tissue-engineering laboratory developed, it was the type of cell (e.g. bone or skin) and not its origin (e.g. human or animal) that was of primary importance. The research focused on controlling cell growth, which could be for a regenerative medicine purpose in which case the source of the cells would need to be human, or it could be for a future consumer product application where it would most likely be animal. The question of source and consent seem to be critical, and although the commodification of human tissue is of ethical concern looked at in another light, we are the only source that can give informed consent. There is also an argument to be made that working with living materials for the manufacture of consumer products has the potential to be more sustainable than our current models, which are still based on the industrial revolution method of 'heat, beat and treat'. (Janine Benyus, cited by Anon, n.d.). This is not to say that all technologies are 'victimless', as discussed through the work of Oron Catts and Ionat Zurr. Currently, much of tissue-engineering uses media containing 'fetal bovine serum' (FBS[9]). However, as with any technology living or otherwise, it should be of the utmost importance to understand its entire impact through a thorough life cycle analysis (LCA).

One of the key concerns raised with biotechnology is the witnessing of a 'resurgence of the application of engineering logic in the field of the life sciences.' (Catts and Zurr, 2010, p.26). Oron Catts and Ionat Zurr, who have been at the artistic forefront of engagement with the ethics of working with living materials for over 20 years, go on to suggest why they believe engineers have become so interested in the life sciences: 'Engineers are interested in synthetic biology (or in biology in general] because the living world provides a seemingly rich yet largely unexplored medium for controlling and processing information, materials, and energy.' (Catts

[9] 'Fetal bovine serum (FBS) is the liquid fraction of clotted blood from fetal calves, depleted of cells, fibrin and clotting factors, but containing a large number of nutritional and macromolecular factors essential for cell growth.' (Johnson, 2019)

and Zurr, 2010, p.26). The concept of life as a factory is not a new phenomenon, from when cells were first discovered it fed into the Cartesian worldview and encouraged science to look at living things as a series of distinct building blocks rather than complex whole organisms. (Capra and Luisi, 2014, p. 37). What is new, is the increasing level of control science has coupled with interest from engineering; 'it seems that whereas previously biologists were employing their understanding of engineering to the life sciences, now it is the engineers who force-fit engineering methodologies into living systems.' (Catts and Zurr, 2010, p. 29). This force-fitting is what is perhaps most problematic - to view technologies such as tissue-engineering through a purely engineering mindset.

It is imperative to mention here that engineering is often a key contributor to the development of any technology, but it should not be the only one. By taking a holistic view and seeing things as connected, whether that is at a cellular level or on a larger macro scale, it is vital to understand that nothing is created or exists in isolation. It is something that every designer, and scientist, should consider - whether they are working with living materials or not - what effect their creations have throughout their life cycle. We should strive to take into account the full effect of a technology and not merely '[...] favor engineering logic over scientific biological knowledge, valuing the language of control and simplicity over the scientific language of uncertainty and complexity.' (Catts and Zurr, 2010, p.30). We should let other disciplines have a seat at the table, which is one of the critical drivers of this research - to introduce a design voice into the conversation, a view that Daisy Ginsberg also shares in her chapter 'Countering the Engineering Mindset' in the book Synthetic Aesthetics (2014, p. 37)

Overall, it is difficult to thoroughly critique that which you do not know, or understand, which was one of the primary motivations for working in a laboratory with the technology itself. It is, therefore, necessary to engage with emerging technologies, and allow thinking to develop through making, as Richard Sennett would have it;

> Pragmatism wants to emphasise the value of asking ethical questions during the work process; it contests after-the-fact ethics, ethical enquiry beginning only after facts on the ground are fixed.
>
> (Sennett, 2009, pp. 295 – 6)

As an increasing number of designers seek to work with living materials in their design practice there is a duty to address this and facilitate broader public debate on its implications. The research model that this PhD adopts aims to develop with this in mind, by purposefully taking

a holistic standpoint in order to engage in the multifaceted implications of utilising living technology for the design.

4.4 Kings College Initial Experiments

This final section of the chapter explores the initial work within the laboratory at the Dental Institute at Kings College London. It covers the first experiments, the design of those experiments, and the processes involved. The initial projects in this research, being speculative in nature, sought to hypothesize a potential future for tissue engineering. With any such imagining, there is a gulf between it and reality – yet the inventive nature of craft could provide a way to realise this imagining;

> So from the fantastical inventions of the Renaissance to the prototypes and renderings of the present, projections of tomorrow are inherently impractical and they require great skill to bring into being, exactly the formula that has long defined modern craft.
> (Adamson, 2012)

If the future is bound up in the potential of biotechnology to grow our materials and products, then it is certainly going to need multitudes of skilled hands to bring it into being. With a realisation that nothing can substitute the tacit knowledge gained from 'hands-on experience' working with specific techniques and materials, as a researcher, I sought to relocate myself into a tissue-engineering laboratory as quickly as possible at the beginning of the PhD. This was a process that took longer than expected, about a year, but it was vital to take the time to find the right laboratory and partner. I found such a relationship in the cell group within the Tissue Engineering & Biophotonics department at Kings College London Dental Institute under the supervision of Professor Lucy Di Silvio. The department's research focus and mission is to provide 'a unique interface between basic and applied research through to clinical translation. The staff in the internationally recognised department are supported by excellent facilities in cell and tissue culture, molecular biology, novel biomaterials development and testing, physical, biological and mechanical characterisation and state-of-the-art imaging facilities, including spectroscopy, multi-photon microscopy and endoscopy.' (Kcl.ac.uk, n.d.). The negotiation of this collaboration proved pivotal in the development of the PhD.

Early conversations were hugely influential, for example during my first discussion with Professor Di Silvio she emphasised the diversity of cellular behaviour and how they can be organised to behave in an orchestrated manner, for example, a simple scratch on the bottom of a culture dish can provide information to cells to align themselves along the scratch. Cells communicate with each other by sending and receiving signals which can be from the environment, e.g. the scratched surface, or from each other. Understanding the link between environmental cues and cellular response remains a much-researched field. Complex conversations are happening at the cellular level, and different bulk surfaces and scaffold structures communicate to cells to behave in a specific manner. Although the influence of the Cartesian view of nature as automata (Capra and Luisi, 2014, p. 25) has been weakening, some sciences appear to have re-embraced the notion of living things as predictable engineerable machines - most notably in the field of synthetic biology. 'The concept of the single engineering paradigm indicates a future in which the control of matter and life would be achieved by applying engineering principals' (Catts and Zurr, 2010, p.26) There are many scientists that have sought to legitimise the practice;

> [...] in Eugene Thacker's words, tissue engineering "… is able to produce a vision of the regenerative body, a body always potentially in excess of itself"[11]—a body that is not dependent on artificial means to fix itself, but is an endless resource. In that respect, TE can be perceived as a 'natural' almost nontechnological technique (although TE is a highly technological application within the biotech industry). Tellingly, although the technique is perceived as 'natural' and dominated by a biological approach, it was named Tissue 'Engineering.'
>
> (Catts and Zurr, 2010, p. 30)

However, with synthetic biology, there is an interesting contrast with '[...] the recent movement of 'real' engineers into the biological field. These engineers coined the term Synthetic 'Biology' to legitimize their approach.' (Catts and Zurr, 2010, p.30). However, the systems view of thinking introduced in the work of Capra and Luisi propounds the importance of a holistic view. A stance echoed by Professor Di Silvio when stressing the importance of interfaces and systems in tissue engineering – nothing in the body exists in isolation, from the cellular level upwards. No part of the body develops without coming into contact with something else, unlike in a culture dish where often only one cell type is grown in isolation. The goal of tissue engineering is to understand how cells, tissues and organs assemble and to recreate functional structures that mimic the natural tissue that can restore, maintain or replace damaged tissues and organs.

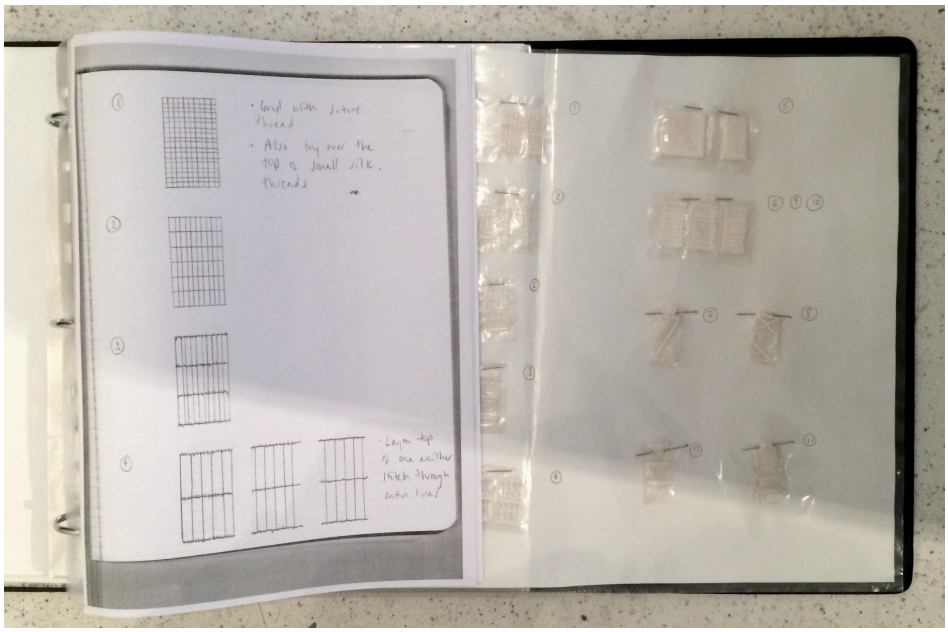


Figure 4.6

Lab notebook pages - showing scaffold designs and samples

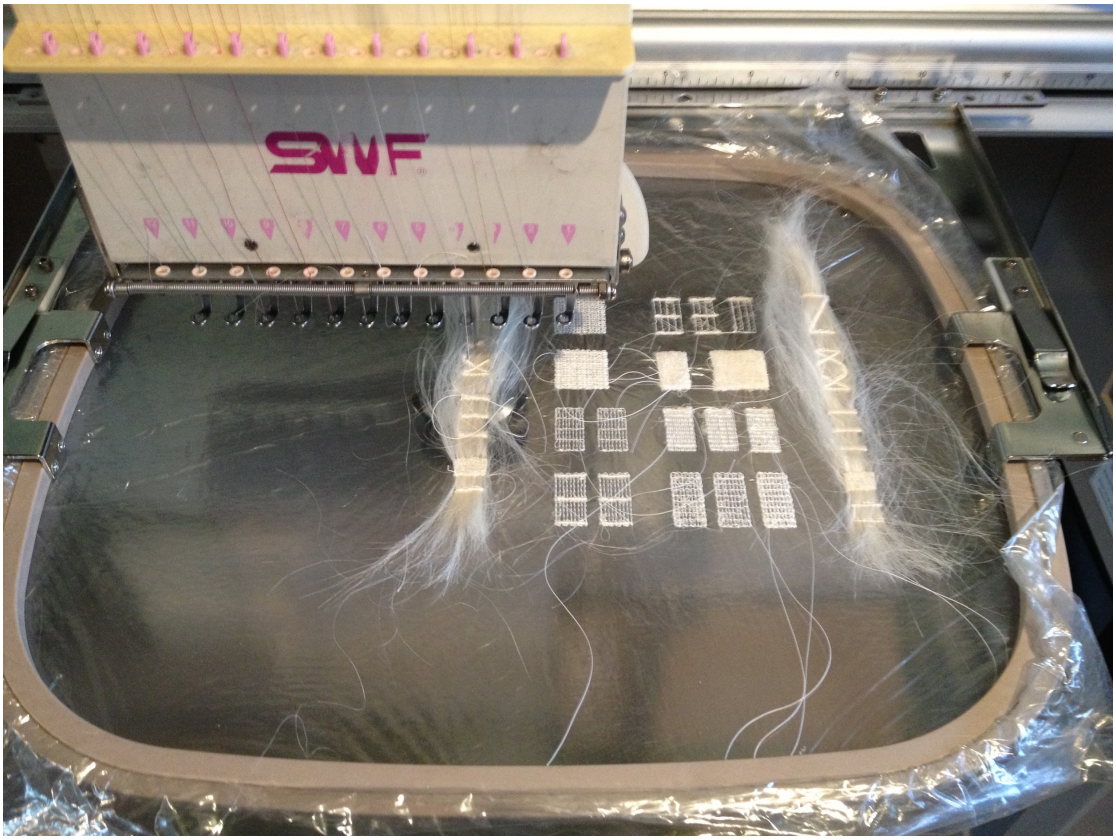


Figure 4.7

Scaffolds being digitally embroidered onto dissolvable fabric

Structures of the Anterior Cruciate Ligament (ACL) inspired the first scaffolds[10] designed for the PhD. They were based on early discussions about the department's research interests after which it became clear that the research could feed into both medical and consumer product applications. Damage of the ACL is an injury that is incredibly difficult to fix effectively due to the complexity of interfaces happening between different tissue types. The scaffolds were designed by researching the structure of the ligament, which was then translated into different embroidery constructs (see figure 4.6). The scaffolds were digitally embroidered, with a 12 head industrial machine, onto dissolvable fabric using Pearsall Silk Suture thread (for a material data sheet see appendix 8) and several scaffolds had silk fibres incorporated into their structure (see figures 4.7 and 4.10). The initial experiments were intended to find out what method of sterilization was most successful, alongside which structures the cells preferred. The naming of the experiments as 'constructed' was intended to be in reference to the textile process of construction and making structures. Below is a summary of the experiment, including notes and results taken from my lab book; for a fully detailed report on the experiment please see appendix 2.

Constructed Experiment 1 (see glossary for technical terms)

Experiment aims:

1. To determine efficiency of irradiation methods. *(See glossary for technical terms)*
2. To assess cell adherence, viability and orientation on the different test scaffolds.

10 "scaffolds essentially act as a template for tissue formation and are typically seeded with cells and occasionally growth factors" (O'Brien, 2011, p. 89)

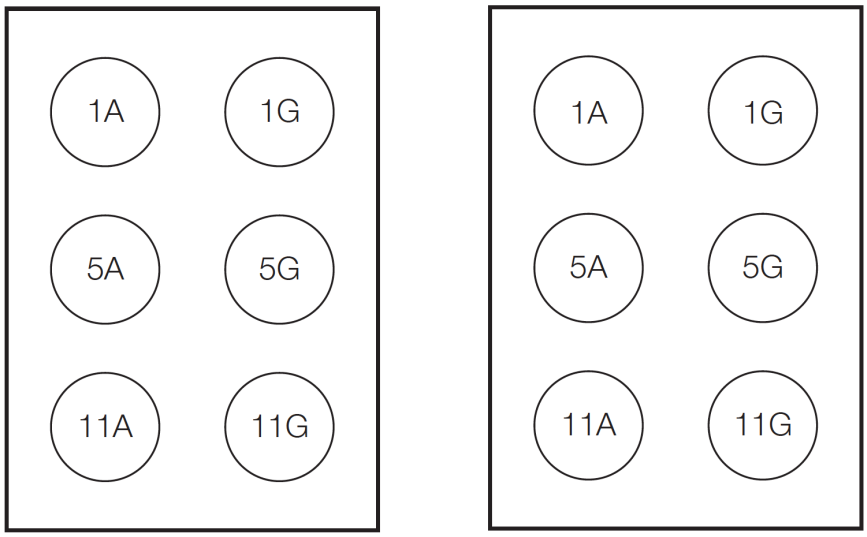


Figure 4.8

Experiment layout design

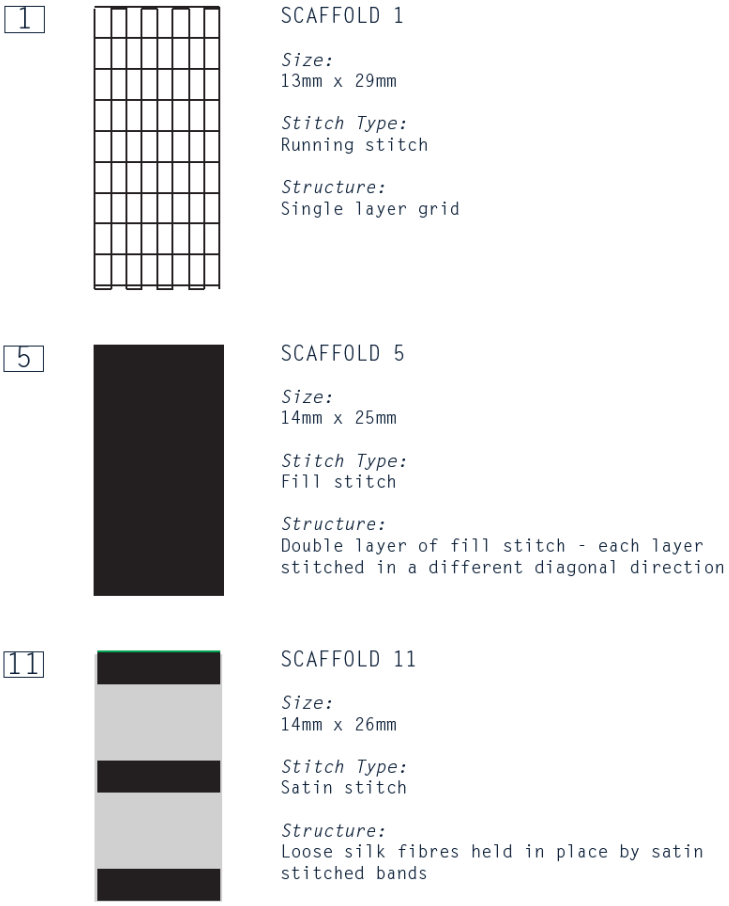


Figure 4.9

Excerpt from scaffold design pages. (The number against each scaffold is the design reference). To view all scaffolds please see appendix 2

Basic protocol:

- Microseed each scaffold with 1ml of 1x 105 HGF1 (human gingival fibroblast) cells
- After seeding leave scaffolds for 4 hours and then add an additional 1ml culture media
- After 24 hours use live and dead staining on each scaffold in plate 1 to ascertain cell viability
- After 4 days use live and dead staining on each scaffold in plate 2 to ascertain cell viability and orientation

Results/ notes (from lab book):

- No discernible difference between autoclave sterilization and gamma radiation. Autoclave sterilization was chosen as method moving forward as it is easily accessible in house at Kings
- The cells appear to attach to all scaffold types, with very few dead cells showing up at 24 hrs or 4 days imaging. Due to the fact that the material needed 2ml of media initially, and 4ml to be covered completely, the scaffolds were only seeded at half the ideal concentration for live/dead imaging
- The scaffolds floated, and it appeared that a number of cells fell through the scaffolds onto the bottom of the well
- Due to the scaffolds floating, some of the cells were not covered in media and therefore died, in particular, scaffold type 5

Suggested design improvements:

- The scaffolds do not need to be so big. Therefore future work will look at a 24 well plate (to reduce the number of flasks of cells needed)
- Weighting of the scaffolds will be investigated to prevent floating
- Use micro-seeding to deliver highly concentrated amounts of cells onto the material.
- Use just one stitch type for the next experiment to develop the most effective protocol, before looking to explore varying stitch types.

As is evident from the notes above, some problems affected the success of the first experiment, the key issues being that some scaffolds floated in the dishes, and when cells become dehydrated they die. After assessing potential solutions, such as weighting down samples, the second round of experiments involved redesigned scaffolds shaped to deal with the constraints of culture dishes. The scaffolds were produced so that they fit snuggly into the wells and thus did not move or float when culture media was added (figure 4.11). Constructed experiment 2 focused on two key parameters: 1) finding the ideal concentration of cells to seed and 2) assessing how well cells adhere to the scaffold.

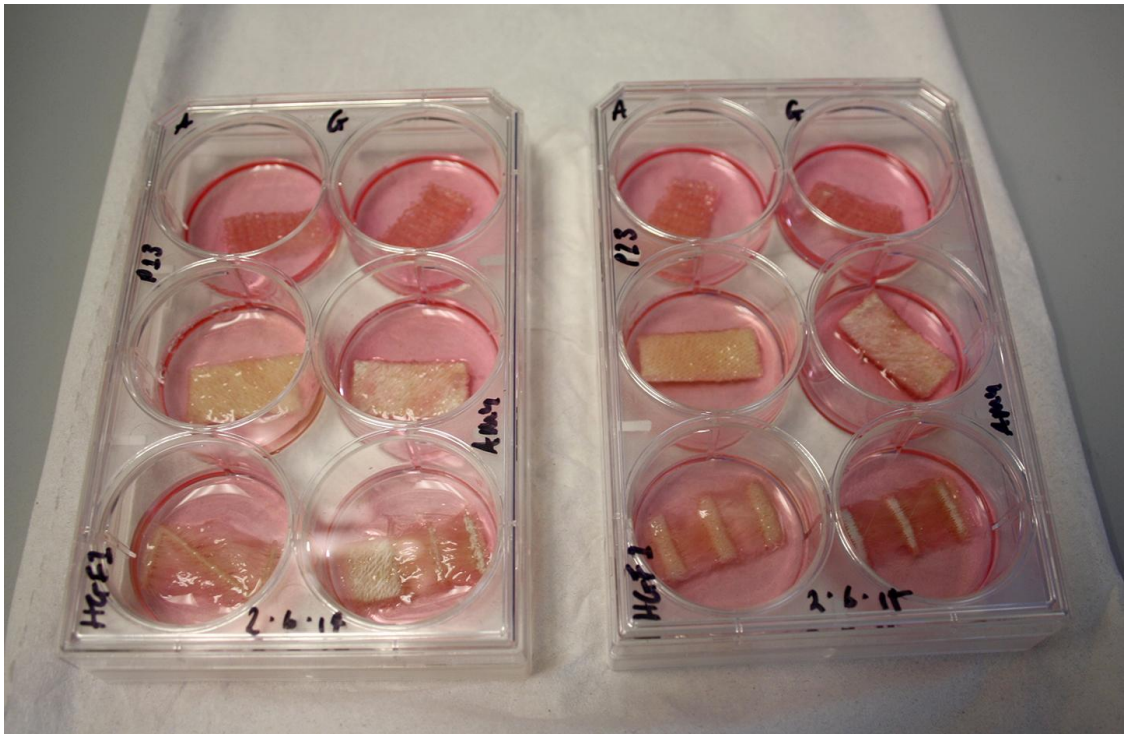


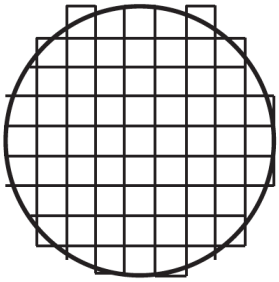
Figure 4.10

Silk scaffolds in culture

Constructed Experiment 2

Experiment Aims:

1. To determine the best concentration of cells to microseed
2. To assess cell adherence, viability, and orientation on the scaffold



SCAFFOLD 13
This scaffold is designed to fit exactly into one of the 24 well plate dishes. It is much smaller than the scaffolds from experiment 1.
Size:
15mm diameter

Stitch Type:
Running stitch, with satin stitch circle over the top

Structure:
Single layer grid

Figure 4.11

New smaller scaffold design

Basic protocol:

- Use two 24 well plates place four scaffolds into each plate
- Microseed two of scaffolds in each plate with 100µl of HGF1 cells at 1x 105, seed the other two with 50 µl at 1x 105
- Leave scaffolds for an hour and then add 900µL of culture media
- After 24 hours use live and dead staining on each scaffold in plate 1 to ascertain cell viability (for the stain use half the recommended amount to help combat scaffold autofluorescence)
- After 4 days use a live and dead stain on each scaffold in plate 2 in order to ascertain cell viability and orientation (for the stain use half the recommended amount to help combat scaffold autofluorescence)

Results/ notes (from lab book):

- Seeding at 100µl was the most successful concentration.
- The cells attached to the scaffold well and there were very few if any, dead cells showing on all of the scaffolds
- By day 4 the cells had proliferated, especially those seeded at 100µl concentration.
- The cells began to show signs of orientating themselves around the scaffolds
- The cells had not fully elongated into a classic fibroblast shape - this could be due to the silicone coating on the silk suture thread

Next Steps (notes from lab book):

- Create scaffolds using plain silk thread to see if the cells elongate and attach better without the silicone coating
- In future experiments consider the use of human osteoblasts (HOB) GFP (see glossary) labelled cells, which would allow the imaging of live cultures as well as allowing the scaffolds to be left in media for a more extended period in order to track how much they continue to orientate themselves and proliferate
- Utilise different stitch types now the basic experimental protocol has been determined regarding scaffold type, media volume and seeding density.
- Longer-term - think about redesigning the culture dishes and weighting systems to allow greater flexibility in designing experiments.

Having developed a scaffold shape, a successful protocol, and ascertaining the best number of cells to seed, the following experiment (number 3) was developed to test a theory that the silicone coating on the suture thread was affecting the morphology (shape) of the cells. The hypothesis was that a plain, uncoated, silk thread would allow for better cell adhesion and allow them to elongate on the threads. For this experiment, a change to the cell type was made. The previous two experiments used HGF - human gingival fibroblasts (skin cells) - the growth of which was stopped at each time point by the process of live dead staining and imaging. The following experiment used GFP + HOB cells (these are human osteoblasts tagged with a Green Fluorescent Protein (GFP), which acts as a biological marker for monitoring physiological processes and allows visualisation of cells). The change of cell type allowed the experiments to run for more extended periods, thus allowing long term monitoring of growth and cell orientation on the scaffolds.

Constructed Experiment 3

Experiment Aims:

- Compare two different silk threads - one silicone-coated suture thread (Pearsalls) and one commercially available silk embroidery thread with no disclosed coating
- Use HOB GFP+ cells to be able to leave scaffolds in culture for more extended periods to assess cell proliferation and orientation

Basic protocol:

- Place three suture thread no. 13 scaffolds and three plain silk no. 13 scaffolds in a 24 well plate
- Microseed each scaffold with 100µL of HOB cells at 1x 105
- Leave scaffolds for an hour and then add 900µL of culture media
- Image each scaffold at the following intervals: 24hrs, 3.5 days, 8 days, 11 days, 15 days - change media at each time interval from 3.5 days onward

Results/ notes (from lab book):

24hrs:

- Cells attached to both the plain silk (Si) and the silk suture (Su) scaffolds, although there appeared to be more cells on the suture scaffolds
- Cells rounded in appearance

3.5 days:

Silk suture:

- Looked healthy, there were some cells on the bottom of each well
- Cells showed signs of proliferation
- Culture media was pale before change, which suggests active cells

Plain silk:

- Very few cells
- Lots of healthy cells on the bottom of the well
- Difficult to focus when imaging
- Media also pale before change, but not as pale as in dishes with suture scaffolds on - this is probably due to there being healthy cells on the bottom of the wells

8 days:

Silk suture:

- Looked to be less cells than before, or they moved further into the thread?
- Turned over scaffolds after imaging

Plain silk:

- Still very few cells
- Cells on the bottom of each well looked unhealthy

11 days:

Silk suture:

- There were concentrated areas of cells
- The cells appeared to be orientating themselves around threads

Plain silk:

- Virtually no cells on scaffolds

15 days:

- Only imaged silk suture scaffolds

Silk suture:

- Appeared to be less cells on scaffold 2
- Still clusters of cells and these looked to possibly have proliferated, but it was difficult to assess
- Lots of cells still attached

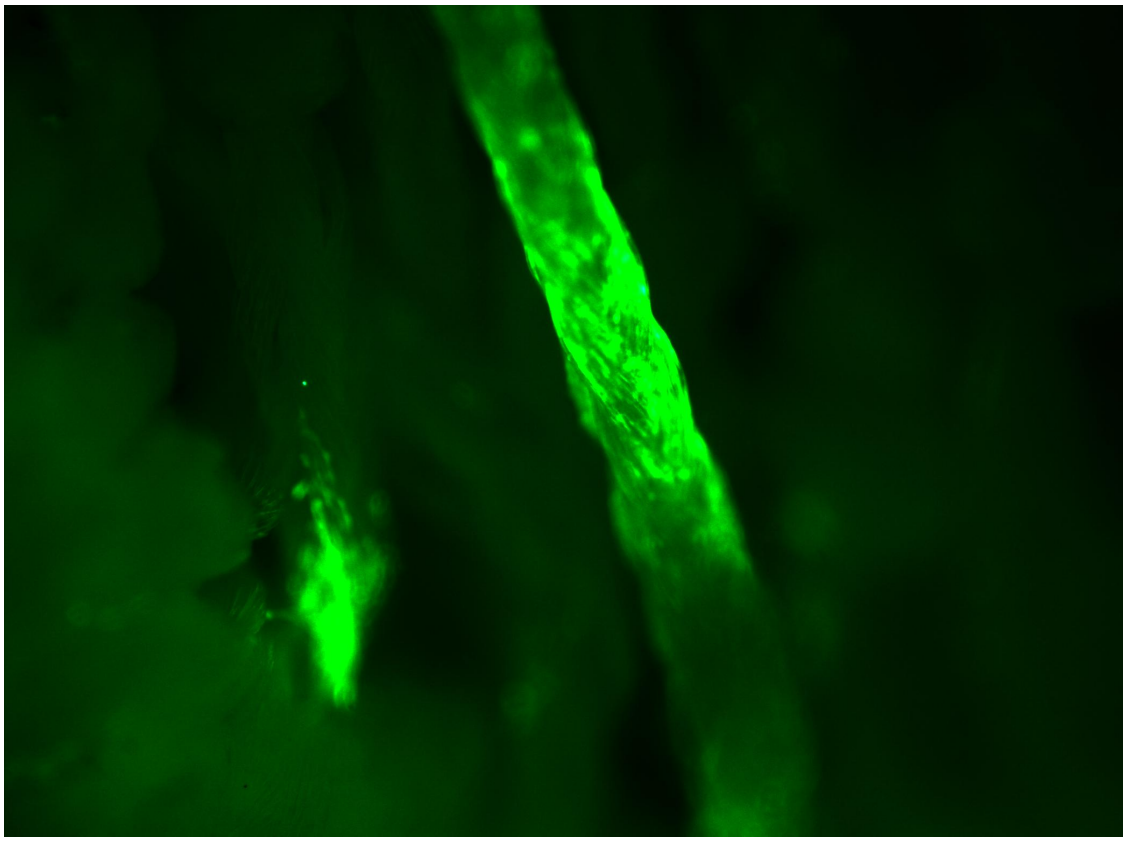


Figure 4.12

Constructed experiment 3, day 11

HOB cells on silk scaffold, x40 magnification, phase contrast imaging and fluorescent imaging (bright green areas indicate cells)

The above experiment tested both silicone-coated suture threads alongside uncoated silk thread. The results of the experiment were unexpected - the cells on the plain silk either attached initially and came off at a later point, or were never adequately adhered, it was difficult to ascertain which. This differed from the hypothesis which was that the HOB (bone) cells would favour the uncoated silk, as previous work with the coated suture threads suggested that cell morphologies were affected by the coating. In contrast to previous findings, the experiment suggested that this was not the case. Outcomes such as this began to highlight the critical role played by the materials used in the creation of scaffolds. It was in search of trying to find more information on materials, and how different cells attached and grew on them, that I discovered a lack of resources in this area. What I was searching for was a material archive of sorts, which I discovered did not exist.

Around the time I was finishing the *Constructed Experiments*, I had been asked to exhibit in a show (Biofabricate 2014). I knew I would not have anything 'grown' in time to show, so I developed a range of informed speculative pieces (see Chapter 6, figures 6.17 – 6.20). To sit alongside these, I wanted a range of materials seeded with cells, and to have microscopic images of the cells growing on them. This element was to ground the speculations in the current research happening in the laboratory. I was extrapolating what the development of the research might facilitate in years to come for future haute couture and performance sport applications. Also, I was thinking about new manufacturing methods that we could deploy such as growing something into place on a piece of fabric rather than using a traditional technique such as appliqué – I was intrigued by the idea of in vitro appliqué. For example, setting a pearl in place by growing bone around it. As a result, the materials I seeded were hard materials such as Swarovski crystals, freshwater pearls, and calcium phosphate (figures 4.13 & 4.14), which could sit alongside the existing results from the thread experiments.

The experiments for Biofabricate were not as extensive as initially intended. During this particular experiment, the cells used became infected, and many of the cultures had to be abandoned. Long term cultures of living cells and handling numerous samples always has potential risks associated with them, for example, cells becoming infected or not responding as expected. The results of the experiment made a prominent example of the fact that working with living systems, such as cell-seeded materials, is by no means predictable (special thanks to Dr Bernadine Idowu for her help in guiding me through the process and helping to conduct the experiment in time for the show).

Constructed Biofabricate Experiment:

Experiment Aims:

1. To seed a small number of materials to test their biocompatibility

Basic protocol:

- Sterilize and place material samples, in this experiment, a freshwater pearl bead, flat Swarovski crystal bead and a sample of calcium phosphate (for this experiment, the material was provided by Dr Neelam Gurav).
- Hold both the Swarovski crystal and pearl down in the well of the 24 well plate by using a light layer of silicone
- Seed each material sample with 100µL of HOS cells at 1x 105
- Leave samples for an hour and then add 900µL of culture media
- Image each material at 4 days

Results/ notes (from lab book):

- The cells attached and proliferated well on all of the materials
- Freshwater pearl was particularly successful

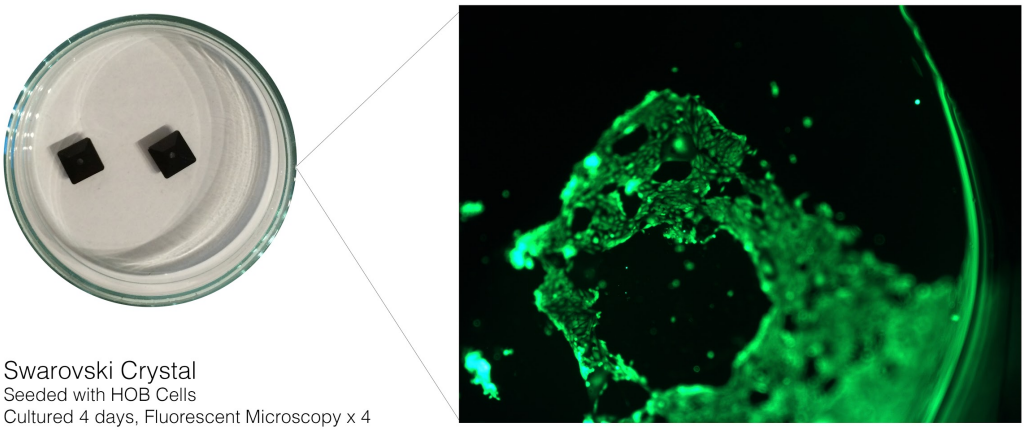


Figure 4.13

Swarovski crystal seeded with HOB cells

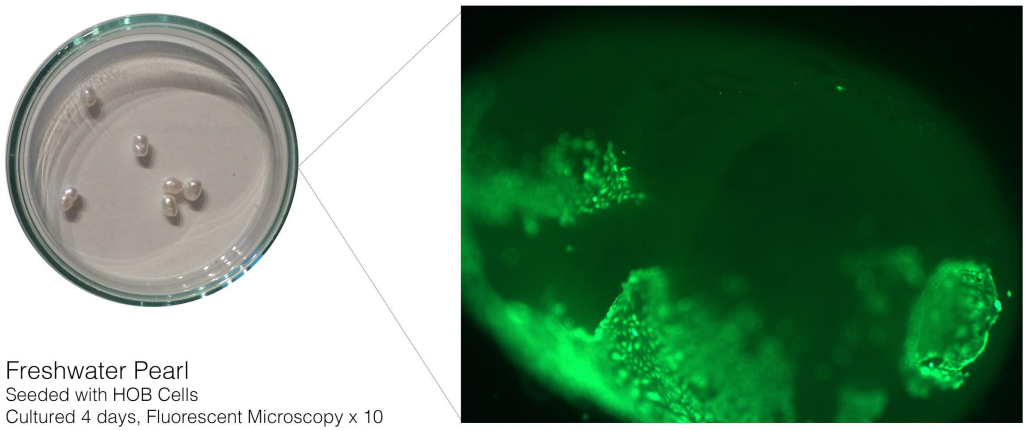


Figure 4.14

Freshwater pearl seeded with HOB cells

After the initial experiments, documented above (figures 4.9, 4.10), several key factors became evident. Firstly, that the scaffolds created were fairly complex in their design and structure. Secondly, that cells behave differently on different materials. The use of varied materials and construction techniques made it difficult to isolate what was causing a scaffold to be biologically compatible. Preliminary experiments were needed to determine what materials were more conducive to cell attachment. For example, cells grew differently on different silks, with coatings playing a part in morphology and proliferation. There was a need, therefore, to take a step back and develop a more thorough understanding through the development of a material archive. The idea of the archive was inspired by the work undertaken for the Biofabricate experiments on different hard materials and being able to compare and contrast them because the same protocol and cells were used. By applying this rigour to different fibres or threads, first seeding them individually, it would develop knowledge as to which were biologically compatible and how they may, or may not, have any effect on cell orientation. From this knowledge, new scaffold structures could be constructed based on the knowledge of which materials aided cell attachment. In addition, all of the scaffolds thus far, have been created using digital embroidery. While this offers a quick, scalable and easily replicable way to make scaffolds, it is also limited in the nature of the stitch it creates; the looping of the top and bottom thread. Added to this, digital embroidery has already been explored to a certain degree

in tissue engineering, and so there was an interest in exploring different textile structures for scaffold creation.

One of the other crucial learning curves that happened when beginning to work in the laboratory, and conducting all the above experiments, was how to ‘design' said experiments (figure 4.15). Developing an experimental design plan requires defining the question that is being asked to support, refute or validate a particular hypothesis. The experimental aim has to be clear, so the results obtained provide an insight into the cause and effect that occur when a particular factor is changed, e.g. natural versus synthetic materials, fibroblast cells versus human osteoblast cells.

My experimental design required defining what I wanted to determine with each experiment and demanded that I explicitly planned strategies to achieve this. This process was alien to my usual style of working; my design process is not often about replicability – experimentation for me is about material sampling, instinct, trial and error. As Daisy Ginsberg writes in ‘Synthetic Aesthetics'; ‘In art and design, I use the "experiment" as an open-ended process to open up and reveal potential ideas; in science, the "experiment" is a tool to generate data to test a hypothesis. Repeating an experiment and achieving the same results is key to the scientific method, whereas experimental process in art often seeks out the exceptional or unique.’ (2014, P. 40) The question repeatedly asked when working with scientists is ‘what do you want to find out?' As a question, this is something I always find possible to answer generally as to what my overarching goals are, but I have often had to work harder when trying to clearly define the specifics of what I hope to ‘verify' experimentally. Much is due to my, predominantly tacit, working practice where I know how to gauge when I am on the right track during the making process. However, applying this method can prove problematic in a laboratory where replicability is paramount.

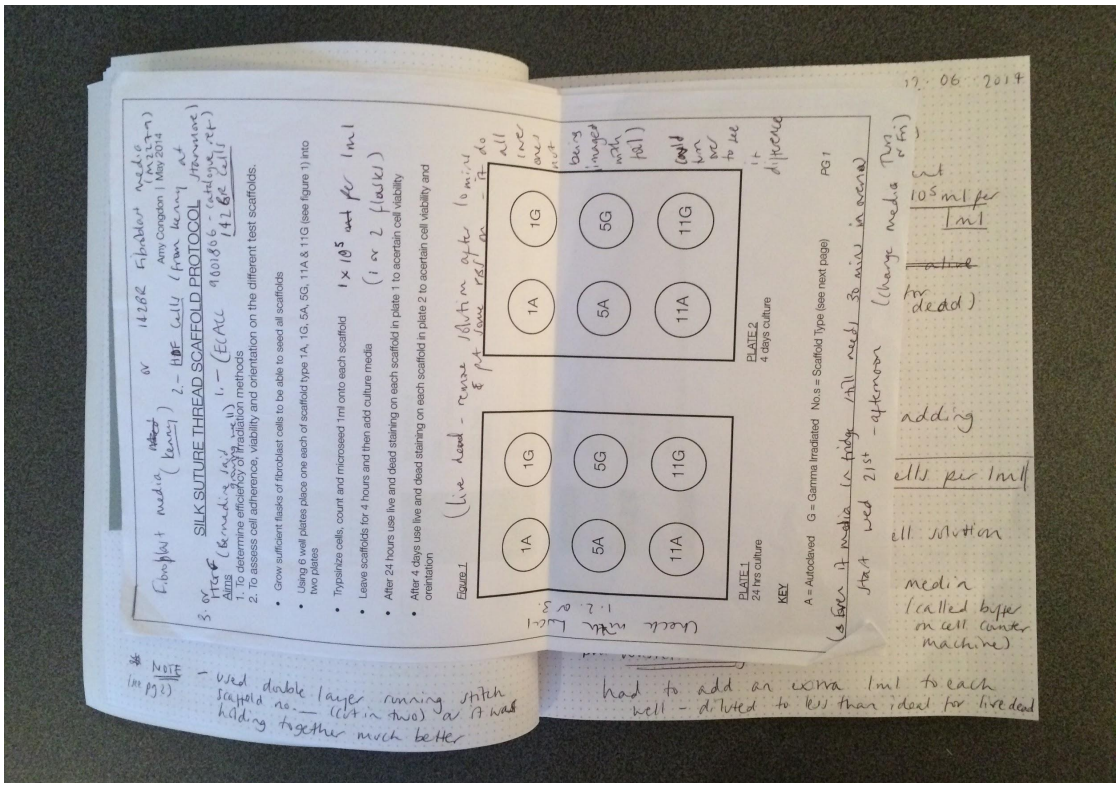


Figure 4.15

Designing experiments in lab book

Keeping a ‘laboratory book' is commonplace in laboratories, but to me, it is another unfamiliar process with its own language. In Bruno Latour and Steve Woolgar's seminal book ‘Laboratory Life' they suggest what an observer of a laboratory might conclude; ‘After several further excursions into the bench space, it strikes our observer that its members are compulsive and almost manic writers’ (Latour and Woolgar, 1986, p. 48). These written accounts are seemingly for the purpose of proving, or disproving hypotheses. Indeed all of my experiments so far have been discarded, having solely been used to trial an idea. All of the issues and insights that have occurred highlight that when reading written accounts of other scientific experiments they are incomplete documents that do not capture how to work or replicate something successfully within the lab. They are at times obtuse and leave much to be guessed at; therefore part of the goal of the lab research was to develop design-led protocols that foreground the importance of embodied knowledge and replicable data. At this point in the research records of achievements were still written documents with accompanying images, and there was still work to do to develop the most effective way to evidence results.

Much of the initial work was about learning from failures, but through this, new methodologies and protocols have emerged. This reactive way of working resonates with Barrett's writings on Bourdieu's ideas on reflexivity;

> Since the researcher's relationship to the object of study (material or mental) is of central concern in practice-based methodologies, they are in accord with Bourdieu's notion of reflexivity. As a result of this reflexive process, methodologies in artistic research are necessarily emergent and subject to repeated adjustment, rather than remaining fixed throughout the process of enquiry.
>
> (Barrett, 2010, p. 6)

Laboratory work has been a process of 'repeated adjustment', and its consistent trial and error approach feels very much like a creative sampling process. There are historical precedents of different approaches to the science of tissue-engineering:

> The contrast between Ross Harrison and Alexis Carrel is striking. Harrison was an experimental embryologist seeking material ground to two opposing theories of nerve growth and cellular autonomy; Carrel was a surgeon, with a much stronger tendency to tinker with tissues in an open-ended way - to see how far one could push them and what would happen when one did - than to experiment in a highly controlled, hypothesis-driven way.
>
> (Landecker, 2007, p. 70)

What Landecker refers to as hypothesis-driven work, seems to be most prevalent in today's laboratories - the process of devising an experiment is top-down, driven by a specific research remit. Whereas the way that Carrel worked was much more iterative, and I would suggest bottom-up in nature - where exploration of a material's capabilities pushed the research. This second approach is much more in line with the way I approached the lab work throughout the PhD, mainly as the work developed (see chapter 5), exploring the capabilities and behaviours of the cells I was working with, and from that understanding, then being able to channel that knowledge into a range of potential applications.

4.5 Conclusion

This chapter covered the transitional practice of the PhD, from the integration of tissue engineering processes into the design studio, through to the beginning of work in the tissue engineering laboratory itself and the ethical issues that accompanied this shift.

The first projects discussed, *DeCellular* and *Haute Bacon*, foregrounded the value of a bottom-up approach; experimenting and pushing with existing techniques and using textile craft processes to explore what possibilities are opened up. In contrast to top-down design, which picks the best technologies and processes for the problem at hand, bottom-up design starts with the technology and experiments with it to see what use it might best be put. One of the most significant learnings to come from these two projects was the value of archiving materials and how they were made. Moving forward to the work in the laboratory it is vital to think about the best way to record and, as a result, disseminate information on techniques and materials, to make it available to a broader audience than just those in the closed community of the laboratory.

The middle section of this chapter sought to cover the ethical considerations, both practical and philosophical, that affect the research. Practically the work needed no approval under the terms of the Human Tissues Act, and as an institution, Kings College London follows strict ethical protocols. However, additional to the issue of ethical clearance, other aspects need to be taken into account; for example, the use of human cells for use in potential commercial applications. This concern, was somewhat changed as the focus of the PhD shifted from the integration of fashion and the body to answer the question of; 'Can the integration of textile craft with tissue-engineering techniques lead to the development of a new materiality for future design applications?' This opens up the possibility of using animal cell lines rather than those from a human source. The other main concern for the field of biotechnology, in general, is the application of the engineering mindset, this research seeks to be more holistic in its approach to working with living materials and supports the inclusion of voices from as many different disciplines as possible.

Finally, the projects detailed were the initial projects undertaken in the laboratory at Kings College London. They documented a practice that has had to adapt to the challenges faced by a non-scientist trying to conduct experiments using methodologies that are somewhat alien to them. What became most apparent during these first experiments was the need to take a step back, and to build knowledge from the ground up; by firstly understanding what materials will cells adhere to and then moving to develop different structures. This understanding of materials and structures is the focus of the work documented in the final chapter of this thesis. Also discussed in this section are the tensions that an iterative approach can cause as it takes a different tack to the hypothesis-driven top-down course typically used in experiment

development. In addition, the difficult task of documenting scientific research, as a designer, was touched upon and how this can be challenging. The aim is that the documentation developed goes some way to achieving a holistic view of the process. The resulting archive is intended to be created from the perspective of a designer working with the techniques of tissue engineering, and the ultimate aim is that it provides the groundwork for the creation of new knowledge for design.

CHAPTER 5:
A Textile Craft Based Laboratory Practice

5.1 Introduction

"Just as early modern artisanal workshops were hotbeds of technical research, artisanal skill was the empirical basis for science itself."

(Adamson, 2013, p. 61)

This chapter covers the concluding research in the laboratory at Kings College London. It details what informed the decision to develop a materials archive and the creation of said resource. The archive, a new contribution to the field, was created to be an entry point and potential resource for designers interested in engaging with living materials in design. The materials seeded broadly cover the textile classification spectrum, from cotton to nylon and milk fibre. What was discovered during these experiments were a number of biologically compatible fibres that have never been used before for tissue engineering applications.

Building on the knowledge gained from the archive, the chapter goes on to present the development of a range of hand-crafted scaffolds which explore how different textile structures can control the orientation of cell growth. The results of this research demonstrate the value brought by a bottom-up textile craft approach to tissue engineering and form the basis for a handcrafted systems-based approach to the technology. Through an understanding of the impact of scale, and with an ability to construct different structures, textiles can be used as a medium through which to create scaffolds for numerous different applications - from regenerative medicine to fashion.

The end section of the chapter concludes with a review of the successes and shortcomings involved in recording results. It highlights the natural tension which occurs between a primarily quantitatively based discipline, such as science, in comparison to the majority qualitative basis of creative practice. How does each discipline mark success and 'prove' what they believe to be true? This final part of the chapter additionally covers the implications of the findings and their importance - particularly concerning scale, orientation and bio selectivity. Overall it is

intended to present the case for the value of bringing in a textile practitioner into the tissue engineering laboratory.

5.2 Top-Down vs. Bottom-up: A Craft Led Methodology for Tissue Engineering

This first section of the chapter covers the methodological approach to the work in the laboratory. It moves on to further expand upon the concepts of top-down and bottom-up as they pertain to the laboratory research. During the initial work at Kings College London, it became apparent that a top-down approach; choosing and replicating a structure found within the body, i.e. the anterior cruciate ligament, was not the most effective way of applying textile craft knowledge and skill. Therefore, the final research undertaken in the lab was a bottom-up engagement with the materials and techniques of tissue engineering - the first stage of which was the creation of a materials archive covering a broad range of fibre types. The second involved combining this knowledge with traditional textile craft skills to create a range of scaffolds that explored controlling the orientation, and alignment, of cells.

Beginning to work in a tissue engineering laboratory, and developing a methodology suited to a textile practice, was a difficult task to navigate. The very term methodology can be one that is intimidating to a designer where, more often than not, ways of working are implicit and emergent. 'The danger in this is that perplexed researchers in art and design will opt to play it safe and, rather than risking the development and defense of really original hypotheses and methodologies characteristic of 'fundamental' research work' (Seago and Dunne, 1999, p. 1) The feeling of being perplexed is compounded even further when the type of research undertaken is dealing with the techniques and methods of a different discipline. This was particularly evident in the early PhD work where a top-down approach to material selection and scaffold creation was used. As a consequence, the concluding work in the laboratory sought to reinterpret the research techniques, and methods, of tissue engineering from a textile viewpoint and a bottom-up approach.

Methodological approach to the lab work

After the initial experiments in the laboratory, detailed in chapter 4, it became increasingly apparent that there was a missing knowledge gap. As a designer and maker, there is firstly a need to understand the materials with which you are working. How do they behave, what are the limitations, and how can they be manipulated to achieve the desired applications By starting straight away, designing complete scaffolds that mimicked tissue, there was a lack of understanding of how the choice of fibre, structure or scale might affect the success of said

scaffold. It is also important here to define success, which, in the case of the scaffolds I was creating, was to show biocompatibility, cell attachment, cell orientation and bio-selectivity. Therefore, the decision was made to go back to basics in the experimentation to learn from the ground up. By working with the constituent parts of scaffolds, fibres and yarns, this allowed the development of an understanding of their properties in relation to cell growth and attachment. For example; do cells attach but is their morphology affected by the material?, do they quickly proliferate and move through the scaffold or stay on the surface?, is any orientation evident and if so what is causing it? By seeding each constituent material independently, one is able to assess how cells attach, if they do, and how they subsequently grow. The approach of being prescriptive and dictating what structure to build, e.g. ACL, removes much of the defining characteristics of an iterative design practice. It makes it difficult to understand the characteristics of cell behaviour and of the materials used. Therefore, an iterative methodological approach was employed in subsequent laboratory work and experiments.

The methodology used in both the material archive and following scaffold experiments can be loosely mapped out as follows - with more specific details found in the ensuing parts of the chapter. Firstly, a decision was made on what materials should be trialled for biocompatibility. These fibres and yarns were then categorised and tested to understand more about them e.g. size. The cell type to be seeded was then chosen, and a protocol developed to carry out the seeding on the materials. The yarns were then seeded with cells and imaged at different time points. Once they had been cultured for the desired amount of time they were fixed, and the results assessed. If necessary, a refinement of the protocol may happen at this point before any repeats are carried out. Refinement happened at numerous points during the final lab work as new processes were attempted and revised based on their success. After the material archive experiments were completed the learnings were fed directly into the development of the scaffold work. For example, the first scaffolds used straightforward textile techniques such as felting and satin stitch to explore what effect fibres in a yarn or non-woven format had on cell orientation. Every experiment built on the results of the one before, with scaffolds slowly becoming a little more intricate as the effects of simpler structures on cell attachment and orientation were understood. Each outcome informed the next set of experiments; which were the most successful materials, and at what scale. This understanding was used as the basis for the scaffold structures and experiments. Then the same iterative working pattern was employed where cells were chosen, protocols mapped out, and scaffolds seeded. In this body of experiments, further refinements happened not just in the protocol but with each round of

samples directly influencing the design and structures trialled in the next set. This iterative approach to working in the laboratory gave a large amount of freedom to purely explore materiality and the behaviour of cells without a prescribed end goal.

Thesis's definition of 'top-down' vs 'bottom-up' in relation to tissue engineering and textile craft

In tissue engineering, nearly all research is funded with the intention of solving a particular problem - there is almost always an end goal in mind. This focus dictates a particular way of working, one which I would argue is 'top-down'. It is important to note here that when referring to 'top-down' and 'bottom-up', this is concerning a methodological approach as opposed to a way of physically building something such as a scaffold (see figure 5.1)

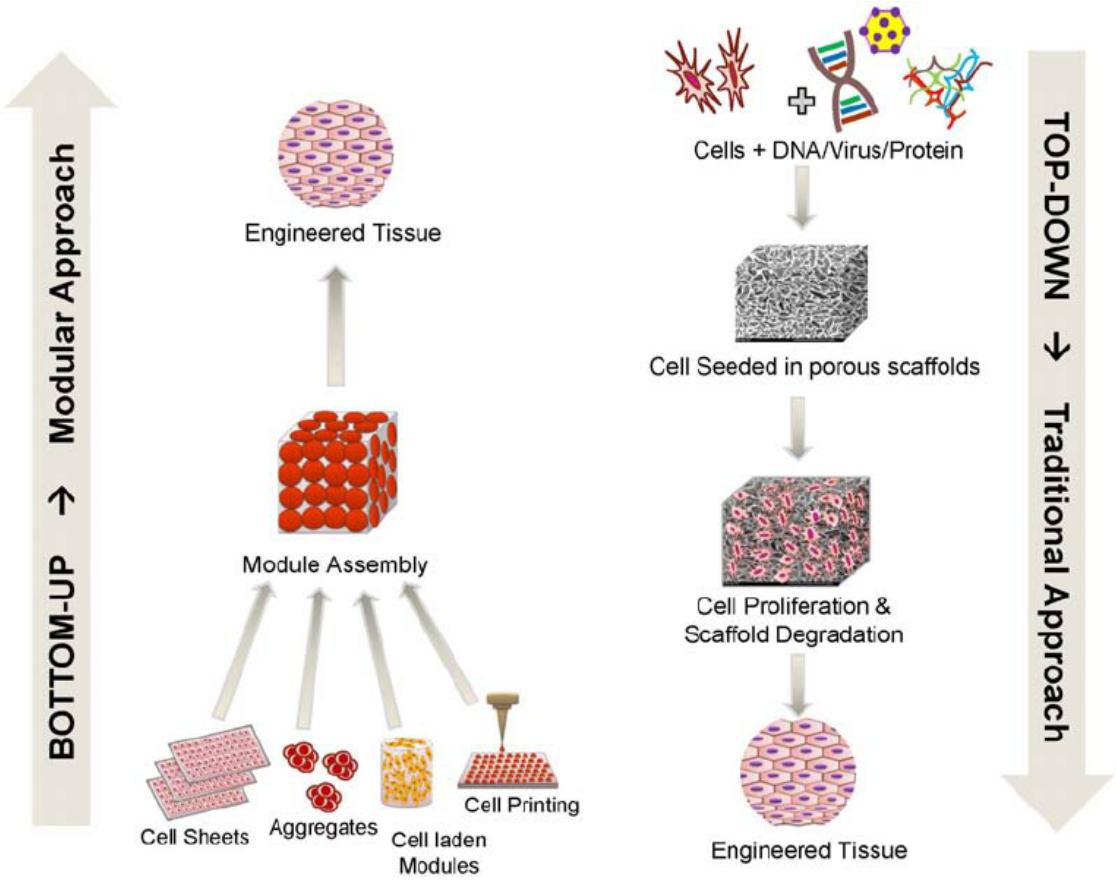


Figure 5.1

"Bottom-up vs. top-down approaches in tissue engineering."

(Annamalai, Armant and Matthew, 2014)

The terms ‘top-down' and ‘bottom-up' are described in engineering terms as the following:

> Top-down: Begin with the design criteria and create components that meet those criteria.
> Bottom-up: Place existing parts and subassemblies into an assembly file; positioning components by applying assembly constraints.
>
> (Knowledge.autodesk.com, 2016)

Taking the above definitions as a starting point, this research's definition of ‘top-down' is that the end product or application is known, and the subsequent methodology involves selecting the correct tools, materials and techniques with which to create the said product. In contrast, ‘bottom-up' is when the end product or application is not known. The methodology, in this case, involves exploring different tools, materials and techniques and then identifying how they could be utilised to create a product/ specific outcome. Following this definition, the vast majority of tissue-engineering research is top-down in nature – a piece of tissue is chosen, and then the aim is to replicate this as closely as possible. What may follow is a bottom-up way of building a scaffold, i.e. piece by piece, but the methodology remains top-down (figure 5.1). The best-known tools, materials, and ultimately, cells, are chosen for the job at hand. A bottom-up approach lends itself to a craft enquiry of material and process; where it is characteristics, and an understanding of those characteristics, that allows a maker to manipulate them in a multitude of ways to obtain the desired outcome.

Inherent within a way of working that is not bound by the constraints of an already identified end goal is a freedom not generally found within laboratories. The notion of freedom of exploration in this way of working and how infrequently it is found in the laboratory is an interesting one and something that I take for granted as a creative practitioner. It is a subject that came up in conversation with the PhD's external supervisor Prof. Lucy Di Silvio:

> So that pressure being removed, there's suddenly this freedom of, "wow, that's interesting, let's look at that. Or maybe we should try that." Whereas you can only do that to a certain extent when you have a defined project. You've got a limited amount of money to do a limited project, you've got to come out with something at the end. And this freedom of being innovative and thinking outside the box, it is a luxury, as far as I was concerned, to be able to think that way.
>
> (Congdon, Di Silvio and Collet, 2018)

Being freed from constraints when working in the laboratory was one of the most productive things that happened in moving the work forward. It allowed exploration that uncovered far

more interesting results than when trying to replicate an existing structure within nature. It is essential to acknowledge that as the quote above states, this type of freedom is a luxury, but I would argue it is an approach to working which can be just as highly effective for material innovation.

This reassessment of how to approach the work in the laboratory led to two new outcomes firmly grounded in a textile craft way of working. The experiments discussed in the rest of the chapter were all born out of bottom-up experimentation focused on being iterative and exploratory. The results achieved are not as rigorous in their pursuit of data as they would be had this been a tissue-engineering PhD. Their value lies in the method of working and how this can help lead to discoveries in this multidisciplinary field.

5.3 Tissue Engineered Textiles: A Material Archive

What became apparent during the earlier laboratory work (detailed in Chapter 4) was that when working with different materials for scaffold creation, all of which were seeded in varied ways with several cell types, it was impossible to discern which variables were having the most significant impact. It was, therefore, crucial to develop a basis of knowledge for what materials cells would grow on and be able to compare like with like knowing they had followed the same protocols. This approach echoes a craft methodology of understanding the behaviours, and characteristics, of the materials you are working with through experimentation. In this case, that encompassed both the textile fibres and the cells. One other essential point to note is that the selection of materials was not limited to those that had a precedent in tissue engineering or that needed to be in any way suitable to be implanted into the body. The overarching goal in this set of experiments was exploration, i.e. not to find necessarily the 'best' material but to understand how they all behaved in culture and to then be able to extrapolate this knowledge for use in scaffold construction. Finally, to my knowledge, there is no other resource that has trialled such a broad range of materials and presented them in such a manner.

When choosing the materials for testing the aim was to select a broad spectrum from across the textile fibre classification types. As shown below (in figure 5.2), the fibre types selected are from both 'natural' and 'engineered' sources. There were ten materials chosen in total:

Natural: Cellulose

1. Cotton

Natural: Protein

2. Mohair
3. Silk Suture Thread (silicone coated)
4. Horsehair

Engineered: Natural Polymer

(Cellulose)

5. SeaCell™
6. Soya

(Protein)

7. Milk

Engineered: Inorganic

8. *Silk* & **Steel** (mixed thread)

Engineered: Synthetic Polymer

9. Nylon Monofilament
10. Polyester

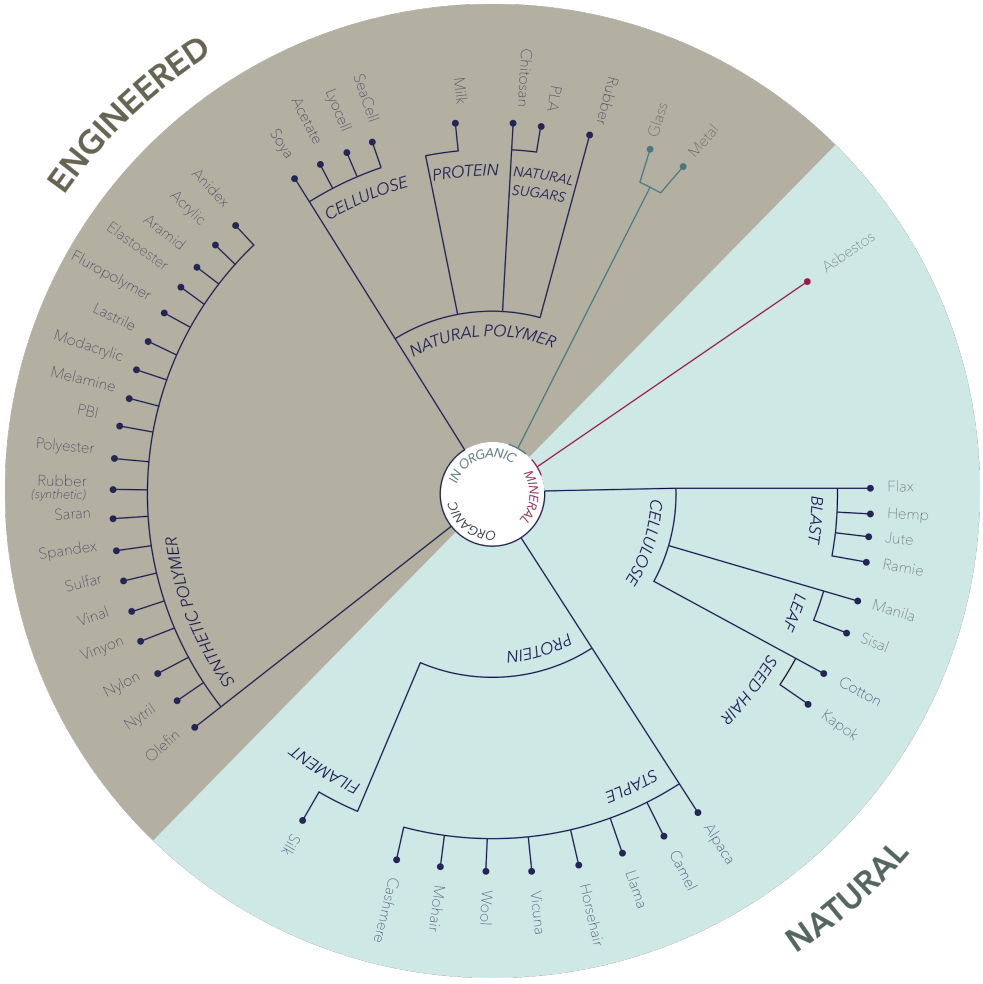


Figure 5.2

Textile Classification chart

Developed and adapted from a chart created by Ayanna Seals (2012)

The overall criteria used in the selection of the different fibre types was first to ensure there was a relatively even split between natural and engineered fibres, and secondly to also select those that have little precedent in the literature. The intention behind the creation of the archive was not to undertake an exhaustive review of all materials; all different types and thread structures of cotton alone could make up an entire PhD. Instead the aim was more qualitative in nature - it was to develop a protocol and knowledge base which is accessible to other textile designers wishing to undertake their own research in the area.

Once the fibre types had been selected, a range of primary characterisation tests were carried out, these were; the size of fibre, if the fibre was wettable, and if they fluoresce under different coloured UV light sources.

Material	*Size - in microns (µm)*	*Wettability*
Cotton	170µm (whole thread)	✓ Coiled in on itself
Milk Tops	12µm (single fibre)	✓
SeaCell™	21µm (single fibre)	✓ Best of all the threads tested
Soya	20µm (single fibre)	✓
Silk & Steel	380µm (12µm single fibre)	✓ Not as successfully as the others
Mohair	600µm (32µm single fibre)	✓ Extremely wettable
Nylon Monofilament	300µm	✓ Material is wettable but will not absorb water and therefore would not absorb media and proteins
Polyester	300µm (whole thread)	✓ Material is similar to the nylon, but a little more hydrophilic
Silk Suture	340µm	✓ Material is similar to the nylon, but a little more hydrophilic

Horsehair	210µm	✓ will submerge in water but not particularly wettable

Table 5.1

Sizes and wettability results

Material	*Fluoresce Green*	*Fluoresce Red*
Cotton	X	✓ (slightly)
Milk Tops	✓	✓
SeaCell™	X	X
Soya	✓	✓ (less than green)
Silk & Steel	X	X
Mohair	✓ (very small amount)	✓ (very small amount)
Nylon Monofilament	✓	✓ (very small amount)
Polyester	✓ (slightly)	✓ (slightly)
Silk Suture	✓	✓
Horsehair	✓ (slightly)	✓

Table 5.2

Fibre fluorescence results

The first measurement; size of fibre (see table 5.1), involved placing each thread on a glass slide and its diameter measured under the microscope in Olympus software. This measurement was recorded to help understand how large each thread/ fibre was in relation to the size of cells, for example, muscle cells can reach up to 100µm (1mm) in diameter whereas a red blood cell has a diameter of approximately 7-8µm (Philips, n.d.). Scale, as discovered through the material archive experiments, is vitally important when looking to control cell orientation.

Some of the sizes listed above refer to the individual fibres; this is where the material was bought as fibre 'tops' and then spun into a thread by hand initially by myself for the first experiments of the archive. In order to keep all materials as comparable as possible, the diameter of each being similar was critical. In order to achieve this, some milk and SeaCell™ fibres, being the most promising from early trials, I commissioned a specialist hand weaver to spin threads of each as close to 200µm in size as possible. Due to the fact that they were created on a domestic spindle, they do vary in size, and the threads themselves are singles and not plied into multiple strand threads.

The second test, wettability (see table 5.1), was used to determine how well the materials took up moisture. The test was carried out by placing a 1 cm section of each thread into a culture dish containing water and examining the results visually. If a material is wettable, or not, is of importance because the more hydrophilic a material is, the better it can absorb the proteins and growth factors in the media, thus supporting cell growth. The expectation is that a wettable material is more likely to be biologically compatible and be attractive to cells. The third and final, test undertaken to characterise the materials was to find out if they autofluoresce (table 5.2). It is important to ascertain this as if they do fluoresce when under the corresponding UV light, then this interferes when imaging the cells after staining with fluorescent dyes.

In seeding these ten materials three different cell types were trialed;

1. HUVEC - Human Umbilical Vein Endothelial Cells
   Endothelial cells line the interior of blood vessels (Alberts, 2002)
2. C2C12 cells - Mouse Muscle Myoblasts
3. HDFB - Human Dermal Fibroblasts
   (Of the above there were problems with the experiments including HDFB cells, they were not growing well, and several researchers were having issues with this particular batch of cells. As a result, they are not included in the following discussions.)

These cell types were chosen for different reasons. The HUVECs were used because they are notoriously selective about what materials they will attach to and therefore if attachment was observed on any of the materials, they were likely very biologically compatible. The C2C12 cells were chosen, as these were representative of soft tissue cells, and they have a specific

morphology and need to be orientated in a certain way to be able to form muscle tissue effectively.

Following the characterisation of the materials, and cell selection, a protocol had to be developed in order to seed the threads. Below is the result - devised through the invaluable direction of a post-doctoral researcher in the Tissue Engineering & Biophotonics Department (Dr Lorenzo Veschini). The protocol involved suspension seeding, essentially shaking the cells and threads together in an Eppendorf tube instead of dropping them on top of materials sitting in tissue culture plate wells. This procedure facilitated cell attachment only to the threads. If they were seeded more conventionally, in plates, there was a likelihood they would settle on the bottom of the plastic culture dish if they missed the material when being added using a pipette.

Thread Seeding Protocol (without gelatin coating)

(2016)

1. Trypsinise cells, count, and then resuspend in the required amount of media - each thread should be seeded with 50,000 cells, in 1ml of media
2. Place each sterilized individual thread (1cm in length) into an Eppendorf tube
3. Pipette 1ml of media with cells into each of the tubes
4. Place tubes in the heated shaker (temp 37°C, speed 600) and leave to shake for 2 hours
5. Remove materials from tubes and place in separate wells of a 24 well plate, pipette media from the tube into the well with the material
6. Culture for 24 hrs, then fix and stain to assess the success of attachment
7. Alternatively, seed duplicate samples for fixing at different time points; 24 hours, 3 days, 5 days and 8 days

Thread Seeding Protocol (with gelatin coating)

(2016)

1. Soak sterilized individual threads (1cm in length) in 1ml of gelatin (0.5% solution in PBS) in Eppendorfs for 1 hour

2. Whilst materials are being coated trypsinise cells, count, and then resuspend in the required amount of media - each thread should be seeded with 50,000 cells, in 1ml of media
3. Remove materials from gelatine and place in new Eppendorfs
4. Pipette 1ml of media with cells into each of the tubes
5. Place tubes in the heated shaker (temp 37°C, speed 600) and leave to shake for 2 hours
6. Remove materials from tubes and place in separate wells of a 24 well plate, pipette media from the tube into the well with the material
7. Culture for 24 hrs, then fix and stain to assess the success of attachment
8. Alternatively, seed replicate samples for fixing at different time points; 24 hours, 3 days, 5 days and 8 days

All of the thread seeding experiments were cultured for 24 hours before being fixed and mounted on glass slides for imaging. The initial screening of all ten materials (Experiment 1, see figure 5.3) showed a number that were reasonably successful, these included cotton and silk suture thread. There was another batch of materials which appeared to support very little, if any, cell growth these were; horsehair, mohair, polyester and nylon monofilament. Of all of the materials, the SeaCell™ was the most successful, followed by milk fibre. Both of these were highly wettable, and the hypothesis is they took up a lot of the proteins in the media and thus supported healthy cell growth. There is also precedent in the scientific literature that cellulose and alginate have been shown to be efficient materials for use in scaffolds and tissue engineering. Both of these materials are found in SeaCell™ fibre, which is made using the lyocell process. The cellulose source is eucalyptus, with the addition of seaweed (alginate) into the fibre at a percentage of around 4% (Product Data Sheet: SeaCell™MT 1.7 dtex 38 or 60 mm, 2016). What is interesting is that there is no mention, found to date, of SeaCell™ being used in tissue engineering previously.

Next, the same experiment was repeated, to verify results, with HUVEC cells and the same ten materials seeded - with the addition to the protocol of coating all of the threads with gelatin to help promote cell adhesion. The cells were labelled with the red tracker (Invitrogen C34552) and once fixed were also dyed with Hoechst fluorescent dye in order to stain cellular DNA. This experiment confirmed the results of the previous one that the milk and SeaCell™ fibres were populated with the most cells at the end of the 24-hour culture period. Once this repeat

experiment had been carried out, a decision was made to focus on the milk and SeaCell™ fibres only, to allow for a more focused exploration of these materials.

Subsequent experiments saw both fibre types being seeded with HDFB (Human Dermal Fibroblasts - skin), HOB (Human Osteoblasts - bone) and C2C12 (Mouse Muscle Myoblasts) cells. In addition to this, the milk and SeaCell™ fibres were seeded with, and without, gelatin-coating to try and ascertain if this made a significant difference to how well cells adhered - the results were not conclusive enough on this front to make a firm decision. The experiments using the HDFB cells were also inconclusive - there were some problems with the growth rate of the cell line used and fewer cells attached than both the HUVEC or C2C12 cells. This could be down to one of two factors; an issue with the cells themselves or that the materials in question are bio-selective (see later in the chapter for more details). The C2C12 cells were therefore chosen because of their specific morphological features and ability to orientate due to their phenotypic nature. The results, as seen in figures 5.4 and 5.5, show definite cell adhesion and evidence of directionality of growth - the cells attached to the individual fibres that make up the threads and grew along them horizontally. This discovery proved invaluable in the creation of the subsequent scaffolds. Further information on all of the thread seeding experiments carried out, and their results, can be found in Appendix 3.

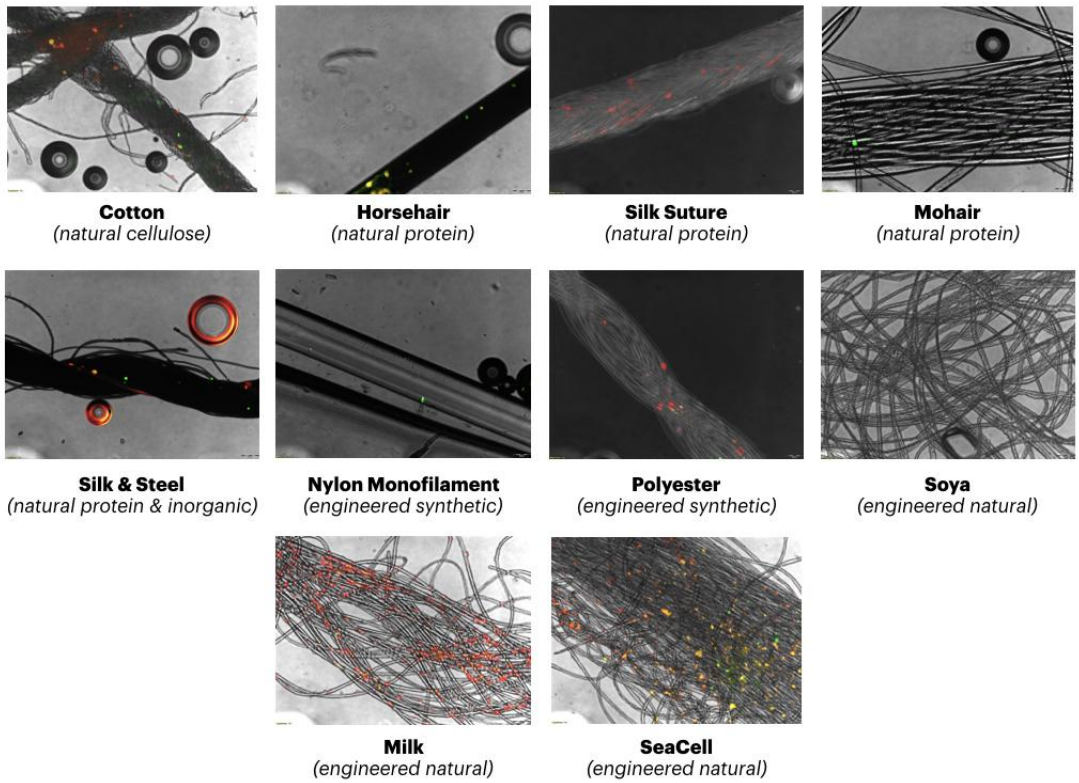


Figure 5.3, 'Results from first Material Archive experiment', 2016

(for larger images see supporting practice documentation)

Images taken from the results of the first experiment, show fixed HUVEC cells on the 10 materials selected, all imaged after 24hrs culture. In the first experiment, 50 per cent of the cells in the experiment were marked with a green cell tracker (Invitrogen C7025) and the other 50 per cent with red tracker (Invitrogen C34552). The reason behind this was to examine whether either of the trackers was toxic to cells so by using both this could be monitored, and, if one tracker did prove damaging to the cells, at least half should remain viable. For all subsequent experiments, the red tracker was used.

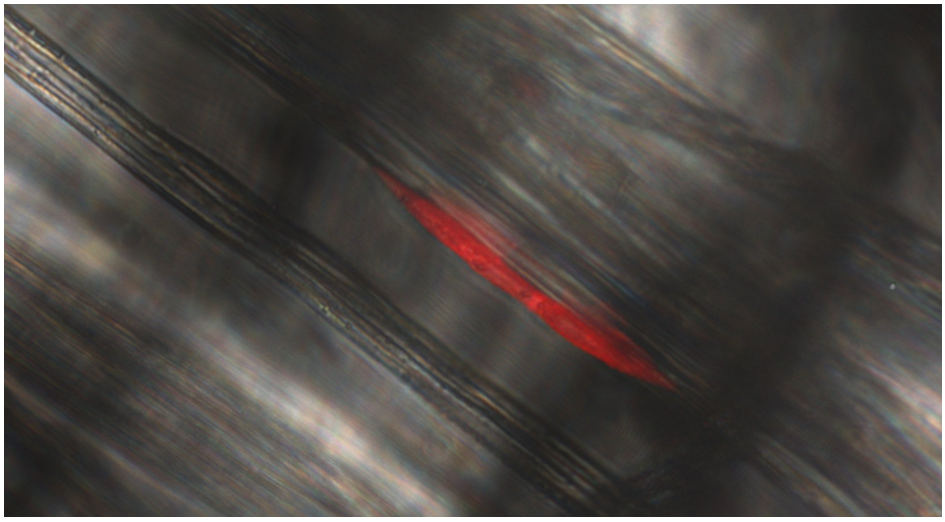


Figure 5.4

C2C12 cell, marked with red cell tracker, seeded onto SeaCell^{TM} fibres, x20 magnification

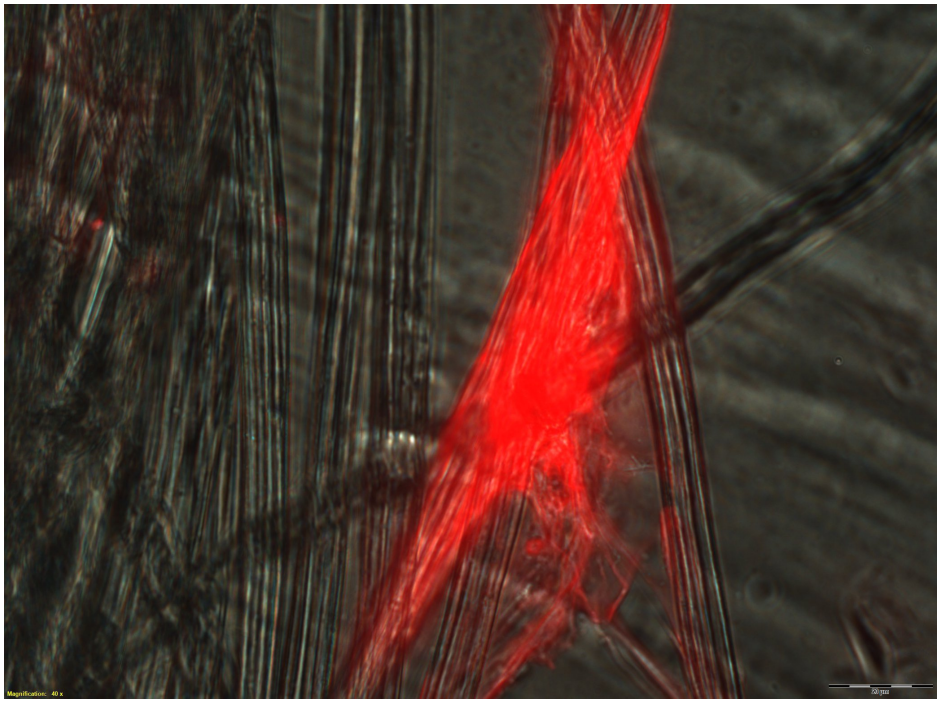


Figure 5.5

C2C12 cell, marked with red cell tracker, seeded onto SeaCell^{TM} fibres, x20 magnification

Documenting the findings from experiments was a complicated process. Documentation, in general, is discussed in the next chapter. The role of the archive is first and foremost to record the experiment accurately; from setup to protocols and results. As discussed previously, I find the vast majority of written methods in scientific papers challenging to follow and often lacking in enough detail. With this in mind, the archive I created was designed to be as comprehensive as possible. As with all documents that aim to record tacit knowledge, it will always be a work in progress to a greater or lesser extent. What should also be highlighted, is that this archive is by nature only the beginning of an ongoing project and, as in any other craft exploration, there is great specificity needed in order to develop methods for all materials. I worked with a selected range of materials and cells, each behaving in unique ways. This is the beginning of understanding, and documenting, the complexities of crafting with living materials. Different threads and different cells and how these interactions will give diverse outcomes. As with any craft practice, one is forever learning about the medium in which one works, what the idiosyncrasies are, and how to work with them. This is perhaps the most fascinating and challenging tension I have seen in the laboratory - trying to create reproducible protocols and to get living matter to behave precisely the same way each time. This goal appears to stem from the application of engineering logic and language onto biology. It gives a researcher the false sense of security that biology can be relatively easily predicated and programmed. While scientific rigour calls for the reduction of variables in an experiment, replicate experiments, and controls, all of this can be done and still the batch of cells with which one is working can behave differently. The battle for consistency and reproducibility is a difficult one to win. Therefore it can be argued that a holistic craft approach could be a valuable voice in how to work with these living materials. What a textile craft approach has already added to this space is the discovery of several materials that do not appear to have been used in the existing tissue engineering literature. The archive is also a commencement towards being the first of its kind; a resource for textile designers wishing to work with different materials in the laboratory.

5.4 Tissue Engineered Textiles: A Hand-Crafted System

> The entire material world, ultimately, is a network of inseparable patterns of relationships. We have also discovered that the planet as a whole is a living, self-regulating system. The view of the human body as a machine and of the mind as a separate entity is being replaced by one that sees not only the brain, but also the

> immune system, the bodily organs, and even each cell as a living, cognitive system. Evolution is no longer seen as a competitive struggle for existence, but rather as a cooperative dance in which creativity and the constant emergence of novelty are the driving forces. And with the new emphasis on complexity, nonlinearity, and patterns of organization, a new science of qualities is slowly emerging.
>
> (Capra, 2015, p. 242-243)

As outlined in the previous chapter, the early research in the laboratory involved the creation of scaffolds using digital embroidery techniques. This technology already has precedence within scaffold production for tissue engineering, as do a number of other textile techniques including weaving and knit (Karamuk, 2001, p. 13). After reassessing where the direction of the practice was heading, it became apparent that the most significant unexplored area of textiles in tissue engineering was in handcraft techniques. Moving back to the handmade was also triggered by a loss of voice as a designer when confronted with unfamiliar technologies and processes of the lab. Working with textile hand techniques was about finding my way back to the concept of the atelier and the techniques of couture.

The aim for the creation of hand-crafted scaffolds was to build on the knowledge generated by the materials archive and which threads were most biologically compatible. The next step was to create, and then seed, a range of scaffolds using various hand textile techniques with the goal of understanding how cells orientate themselves around different structures. The different types of handcraft techniques used included;

- Weaving
- Crochet
- Macramé
- Braiding
- Embroidery
    - French knots
    - Couching
- Lace making
- Wrapping

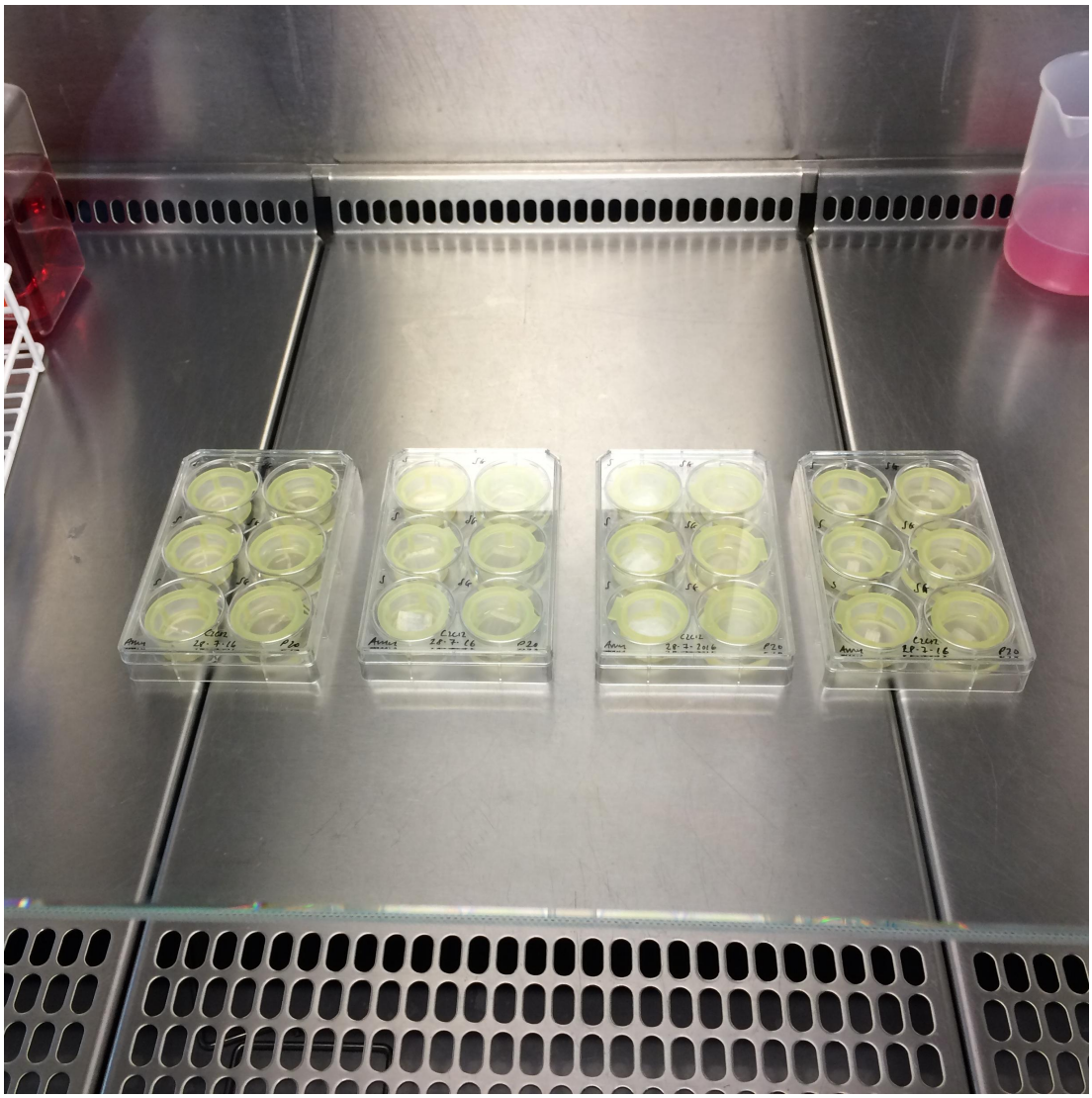
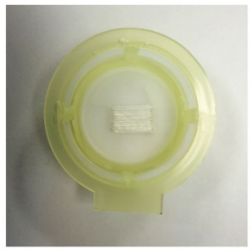
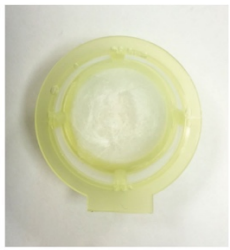
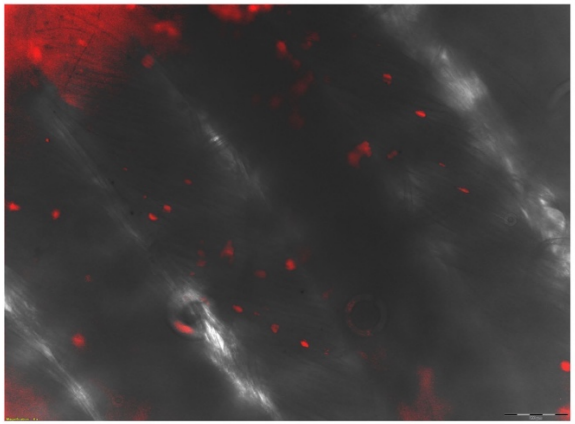
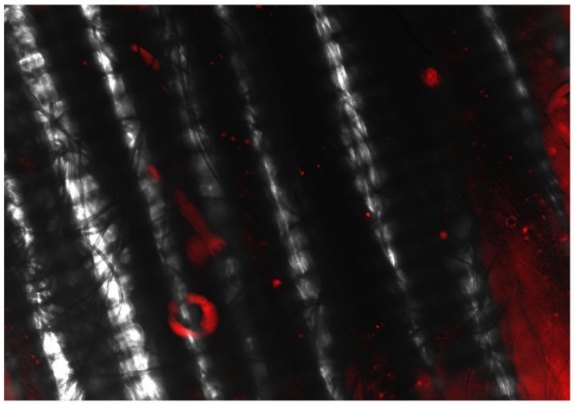
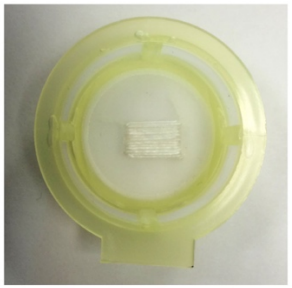
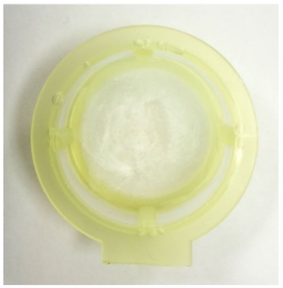
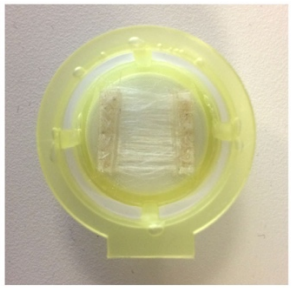
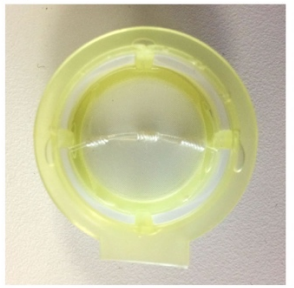


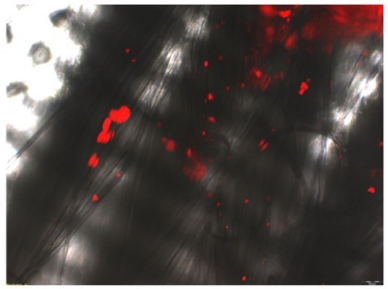
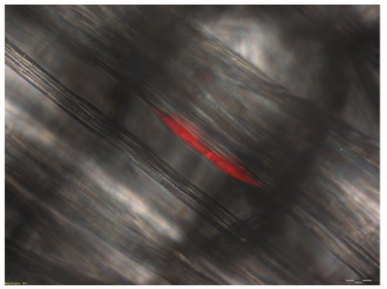
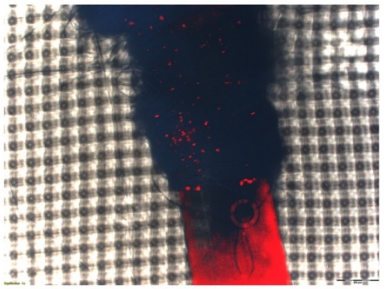
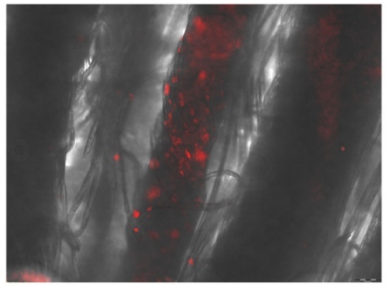
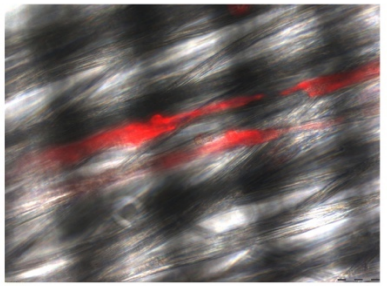
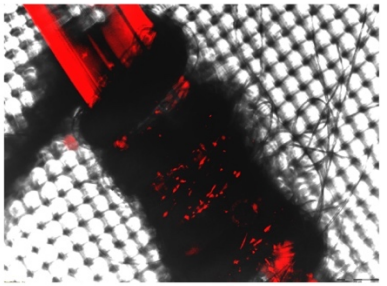
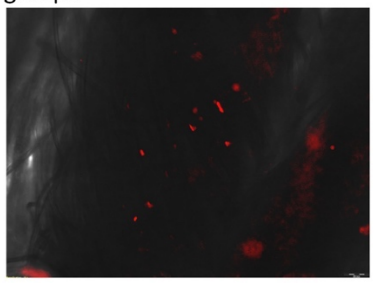
Figure 5.6

Duplicate scaffolds prepared for seeding with C2C12 cells, Experiment 2, 2016

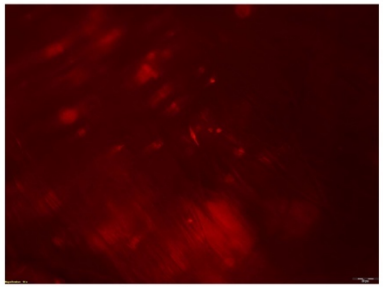
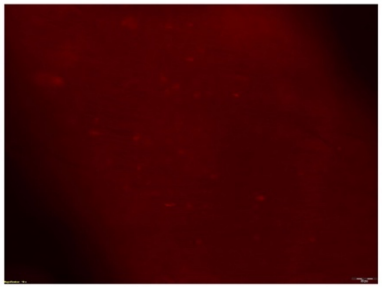
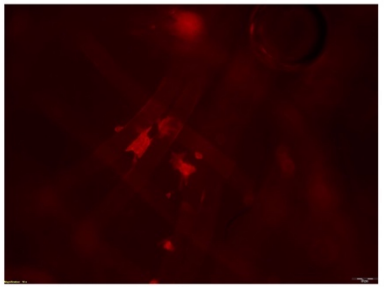
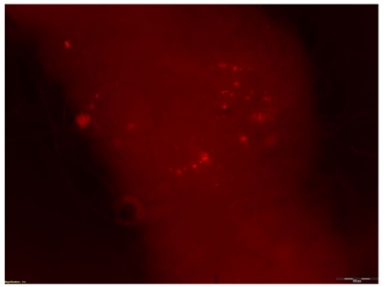
EXPERIMENT 1		
Seeding method	Microseeding	
Cell type	C2C12	
Scaffold materials & structures	SeaCell™ - Satin Stitch 	SeaCell™ - Needle punched felt 
Replicates	x6 of each scaffold: • *x3 gelatin soaked pre seeding* • *x3 no pre treatment*	x6 of each scaffold: • *x3 gelatin soaked pre seeding* • *x3 no pre treatment*
RESULTS		
24 hours	Some cells attached to threads - rounded in morphology *(Problem with microscope - unable to take images)*	No cells visible: • Unable to tell if this is due to density of felt not allowing light through • That no cells attached • Cells died due to being dry (*Unable to image scaffold)*

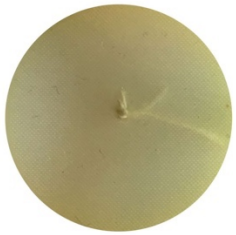
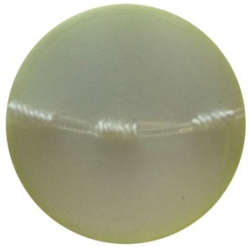
4 days	Some cells attached, localised and still rounded 	No cells visible: ● Unable to tell if this is due to density of felt not allowing light through ● That no cells attached ● Cells died due to being dry (*Unable to image scaffold)*
8 days	Some cells attached, localised and still rounded. Did not appear to be any noticeable proliferation of cells. 	No cells visible: ● Unable to tell if this is due to density of felt not allowing light through ● That no cells attached ● Cells died due to being dry (*Unable to image scaffold)*

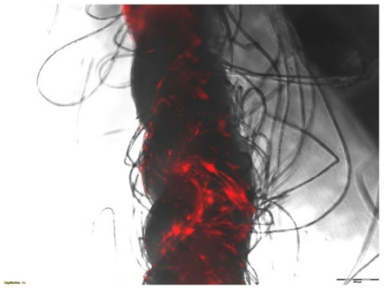
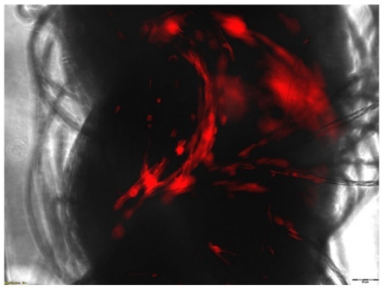
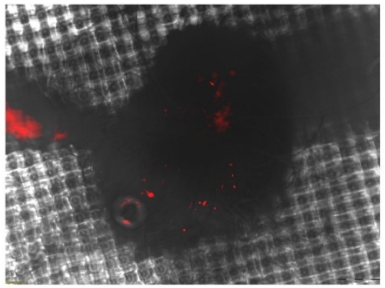
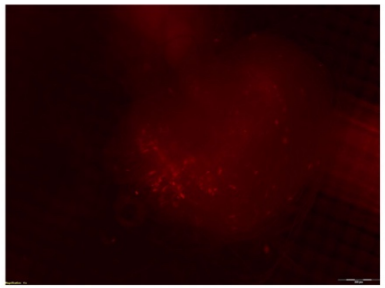
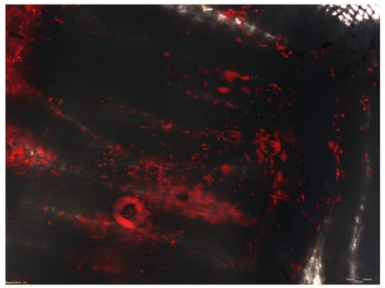
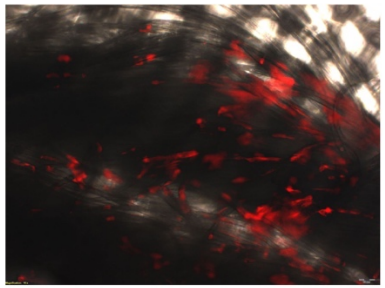
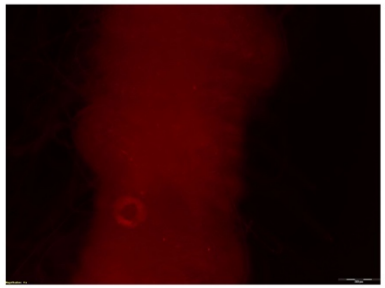
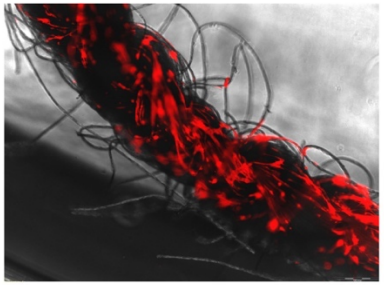
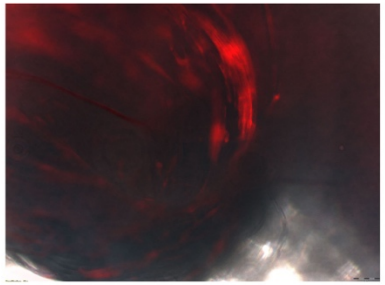
EXPERIMENT 2				
Seeding method	Flood Seeded *Due to only a few cells being attached - the seeding method was re-evaluated. Scaffolds were flooded with media containing cells and rocked periodically for 45 minutes*			
Cell type	C2C12			
Scaffold materials & structures	SeaCell™ – Satin Stitch 	SeaCell™ - Needle punched felt 	SeaCell™ - Trapped fibres 	Nylon Monofilament Couched w/ SeaCell™ 
Replicates	x6 of each scaffold: ● *x3 gelatin soaked pre seeding* ● *x3 no pre treatment*	x6 of each scaffold: ● *x3 gelatin soaked pre seeding* ● *x3 no pre treatment*	x6 of each scaffold: ● *x3 gelatin soaked pre seeding* ● *x3 no pre treatment*	x6 of each scaffold: ● *x3 gelatin soaked pre seeding* ● *x3 no pre treatment*
RESULTS				
24 hours	Some cells attached, a few orienting along fibre but majority are rounded	Re-tried seeding needle felt to see if a less dense scaffold would allow imaging, or if a	Very few cells attached. Those that are have elongated along the fibres	Cells attached only to the SeaCell™, majority rounded in shape.

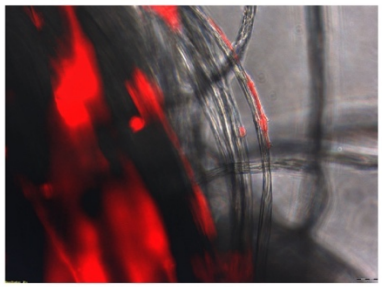
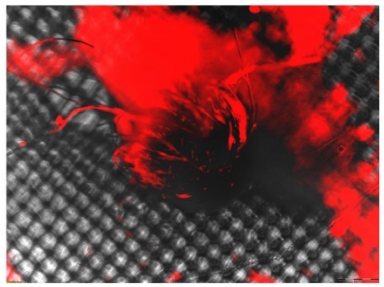
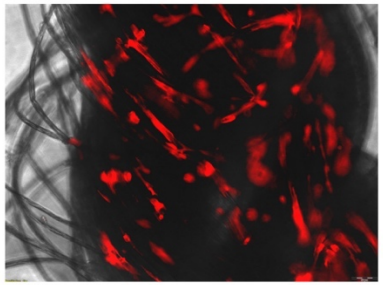
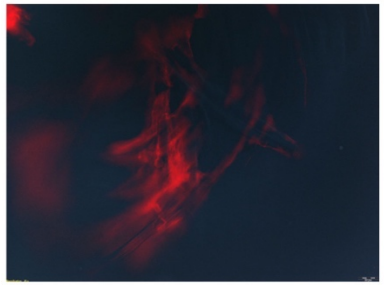
		different seeding method would be more successful. *(Unfortunately, as with previous felt scaffold no cells were visible to image)*		
5 days	Cells locally attached on certain areas of threads. Where grouped they appear to have proliferated 		Still very few cells attached. Those that are have elongated along the fibres. 	No cells on the mono. Cells have proliferated elongated and are growing around SeaCell™ fibres. 
8 days	Same as 5 days - localised cell groups 		Still very few cells - hypothesis is there were too few that attached initially and therefore they did not proliferate well *(No image taken due to lack of cells)*	No cells on the monofilament and cells growing around SeaCell™ fibres. Appears to have been some proliferation *(Image lost due to microscope issue)*

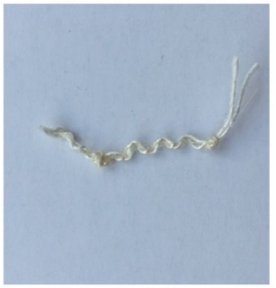
EXPERIMENT 3				
Seeding method	Suspension Seeded *Scaffolds were made on strainers and then cut out from frames. They were then suspension seeded in eppendorf tubes*			
Cell type	C2C12			
Scaffold materials & structures	SeaCell™ fibres - Couched w/ nylon monofilament 	SeaCell™ fibres - wrapped around nylon monofilament core 	SeaCell™ - Trapped fibres, tacked down w/ nylon monofilament 	Macramé with SeaCell™ thread around nylon monofilament core 
Replicates	x3 of each scaffold: *All gelatin soaked pre seeding*	x3 of each scaffold: *All gelatin soaked pre seeding*	x3 of each scaffold: *All gelatin soaked pre seeding*	x3 of each scaffold: *All gelatin soaked pre seeding*

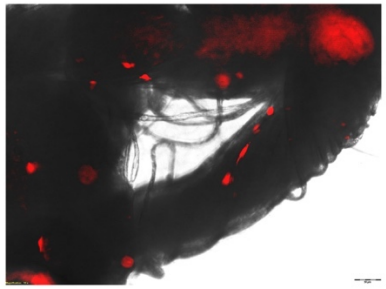
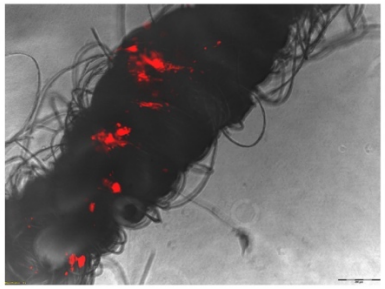
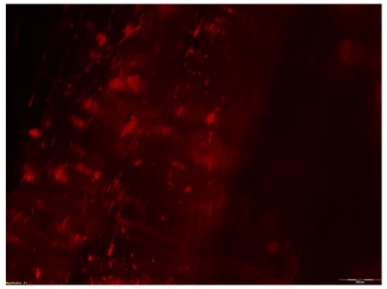
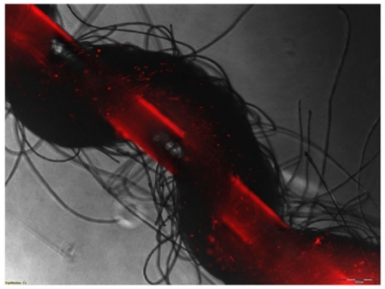
RESULTS				
24 hours	Some cells visible on SeaCell™ fibres - none on monofilament  *(Problem with microscope - only able to take fluorescent images)*	Some cells, less than couched, visible on SeaCell™ fibres - fairly rounded shape  *(Problem with microscope - only able to take fluorescent images)*	Very few cells visible - a small number attached between individual fibres  *(Problem with microscope - only able to take fluorescent images)*	Some cells visible - most concentrated in bottom ridge of macramé  *(Problem with microscope - only able to take fluorescent images)*
4 days	Some cells visible on SeaCell™ - with suggestion of some proliferation *(Problem with microscope - unable to take images)*	A number of cells visible - embedded with SeaCell™ fibres *(Problem with microscope - unable to take images)*	Still very few cells visible *(Problem with microscope - unable to take images)*	Cells elongated in places and majority sitting along bottom of ridge in macramé *(Problem with microscope - unable to take images)*
8 days	Some elongated cells - only on SeaCell™, with some proliferated. *(Problem with microscope - unable to take images)*	Cells somewhat elongated & some suggestion of proliferation *(Problem with microscope - unable to take images)*	No apparent proliferation - limited number of cells *(Problem with microscope - unable to take images)*	Cells still visible - not a large amount of further proliferation evident *(Problem with microscope - unable to take images)*

EXPERIMENT 4				
Seeding method	Suspension Seeded			
Cell type	C2C12			
Scaffold materials & structures	SeaCell™ thread - 3 stranded braid 	SeaCell™ thread - French knot 	SeaCell™ threads - Satin stitch 	SeaCell™ thread - Couched over nylon mono core 
Replicates	x3 of each scaffold: *All gelatin soaked pre seeding*	x3 of each scaffold: *All gelatin soaked pre seeding*	x3 of each scaffold: *All gelatin soaked pre seeding*	x3 of each scaffold: *All gelatin soaked pre seeding*
RESULTS				
24 hours	A large amount cells attached to, and elongating along, the individual fibres within braid. Most successful scaffold so far at 24 hr stage	Cells attached to the knot - rounded in morphology *(Some problems with microscope - where I was only able to take fluorescent images)*	Large number of cells attached to individual fibres in threads - morphology in between rounded and elongated	A reasonable number of cells attached - rounded in morphology and appear to be almost 'embedded' within fibres - difficult to image *(Some problems with microscope - where I was only able to take fluorescent images)*

	 	 	 	
4 days	Cells appear to have proliferated and are elongated along the individual fibres - they have a long branch like morphology 	Cells have proliferated and have changed from the rounded morphology, becoming elongated and following the direction of fibres 	Cells appeared to have proliferated and are still elongated along individual fibres *(Image lost due to microscope issue)*	Difficult to tell if cells have proliferated - still relatively rounded in morphology *(Image lost due to microscope issue)*

				
9 days	Scaffold still highly populated with cells which are long in morphology and following the direction of the scaffold 	Scaffold still highly populated with cells which are long in morphology and following the direction of the scaffold 	Cells appeared to have proliferated a little more and are still elongated along individual fibres *(Image lost due to microscope issue)*	Looks as though there are less cells - not sure if they have migrated into scaffold or have not proliferated any further *(Image lost due to microscope issue)*

EXPERIMENT 5				
Seeding method	Suspension Seeded			
Cell type	C2C12			
Scaffold materials & structures	SeaCell™ threads - Crochet 	SeaCell™ thread - Macramed 	SeaCell™ fibres - trapped (not on cell strainer backing) 	SeaCell™ thread (2 strands) & nylon mono (1 strand) - Braid 
Replicates	x3 of each scaffold: *All gelatin soaked pre seeding*	x3 of each scaffold: *All gelatin soaked pre seeding*	x3 of each scaffold: *All gelatin soaked pre seeding*	x3 of each scaffold: *All gelatin soaked pre seeding*
RESULTS				
24 hours	Some cells attached to scaffold, some slightly elongated	Some cells attached and are sitting in the valleys between threads which are created through macrame technique	A large number of cells attached and embedded within scaffold structure - elongated along fibres	A good amount of cells attached only on the SeaCell™ - no cells visible on nylon monofilament *(Autofluorescence of monofilament makes whole thread look red)*

				
4 days	Cells have elongated slightly and have proliferated a small amount. Following fibre directionality *(Problem with microscope - unable to take images)*	Cells elongated slightly and proliferated a small amount within valleys of scaffold *(Problem with microscope - unable to take images)*	Lots of cells still attached and elongated along individual fibres. Also connected across between fibres *(Problem with microscope - unable to take images)*	Cells still only growing on SeaCell™ - elongated further than they were at 24 hours. Some suggestion of proliferation *(Problem with microscope - unable to take images)*
9 days	Cells have proliferated a little more - may be difficult as there are large gaps between different parts of the structure? *(Problem with microscope - unable to take images)*	Cells appear to have not proliferated much more - may be confluent within the valleys where they are attached and therefore not dividing *(Problem with microscope - unable to take images)*	Lots of elongated cells still attached, unsure if there has been further proliferation *(Problem with microscope - unable to take images)*	Good number of cells still attached - no cells visible on the nylon monofilament *(Problem with microscope - unable to take images)*

All of the scaffolds made using the techniques listed above were constructed using SeaCell™ threads and fibres, with some nylon monofilament components, and in most experiments were seeded with C2C12 muscle cells. Initially, the protocol developed to seed the scaffolds involved microseeding. However, it was altered to follow the same steps as the thread seeding so that it was directly comparable. This protocol involved cutting the scaffolds free of the 'frames' upon which they had been constructed (see the difference between scaffolds in Experiment 1 table and Experiment table 3). Each scaffold was made in duplicate to facilitate numerous time points being trialled. Growing the cells for more extended periods of time allowed the experiment to show at 24 hours, if the cells had attached and then at time points of 72 hours (3 days), 120 hours (5 days) and between 192 hours (8 days) to 216 hours (9 days) if they proliferated and orientated around the scaffolds.

As mentioned in the previous paragraph, the scaffolds were constructed on 'frames'. These frames were cell strainers (see figure 5.7). Cell strainers are used in tissue culture to sieve and separate cells of a specific size, using a plastic frame and mesh. However, they are remarkably similar to embroidery hoops. They were used either to construct the scaffolds when they needed a backing, e.g. french knots (figure 5.8) and were also useful in anchoring scaffolds to prevent them from floating in the culture media. There was an intention, before this final stage of lab work, to create bespoke tools for work in the laboratory. However, as discussed in the following chapter, there were several reasons why this was not possible. It was, therefore, interesting to repurpose existing tools in order to achieve the goals of the research.

Figure 5.7

'Cell Strainers'

Figure 5.8

Embroidering a french knot, in SeaCell™, into a cell strainer

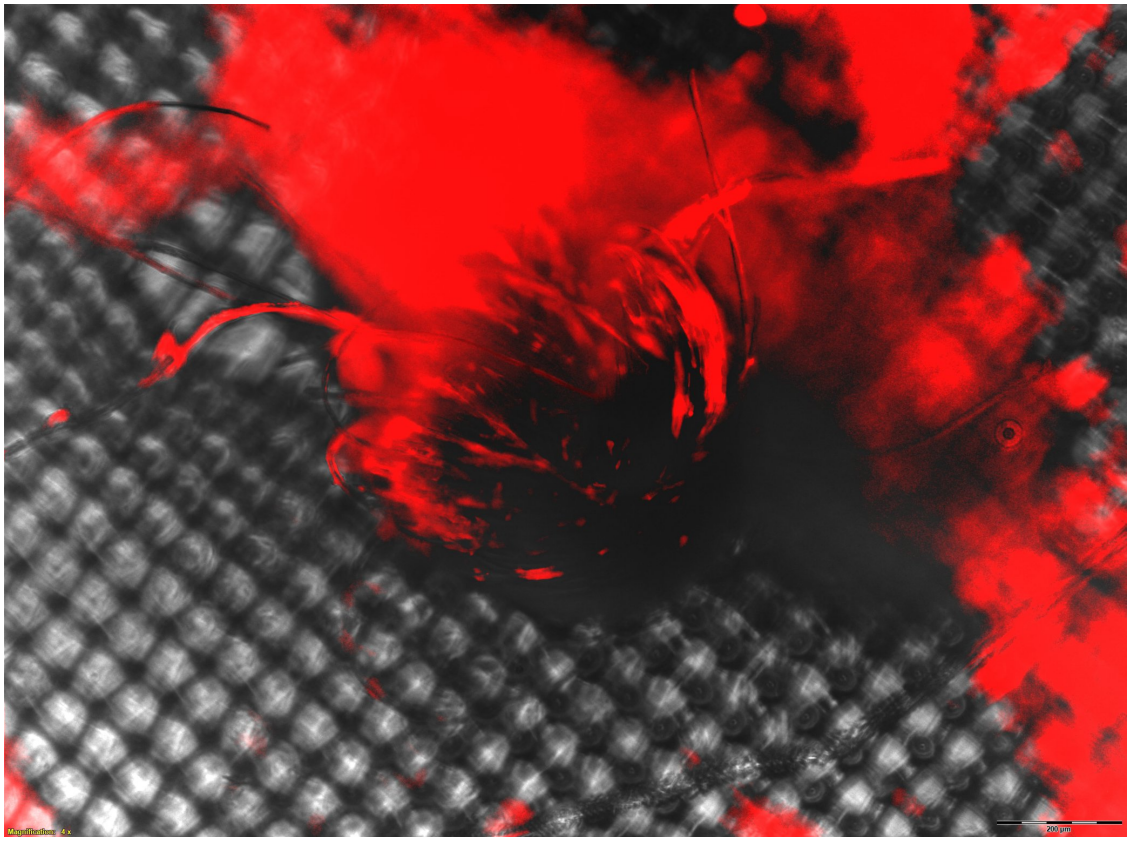


Figure 5.9

SeaCell™ french knot, seeded with C2C12 cells, 5 days in culture, x4 magnification

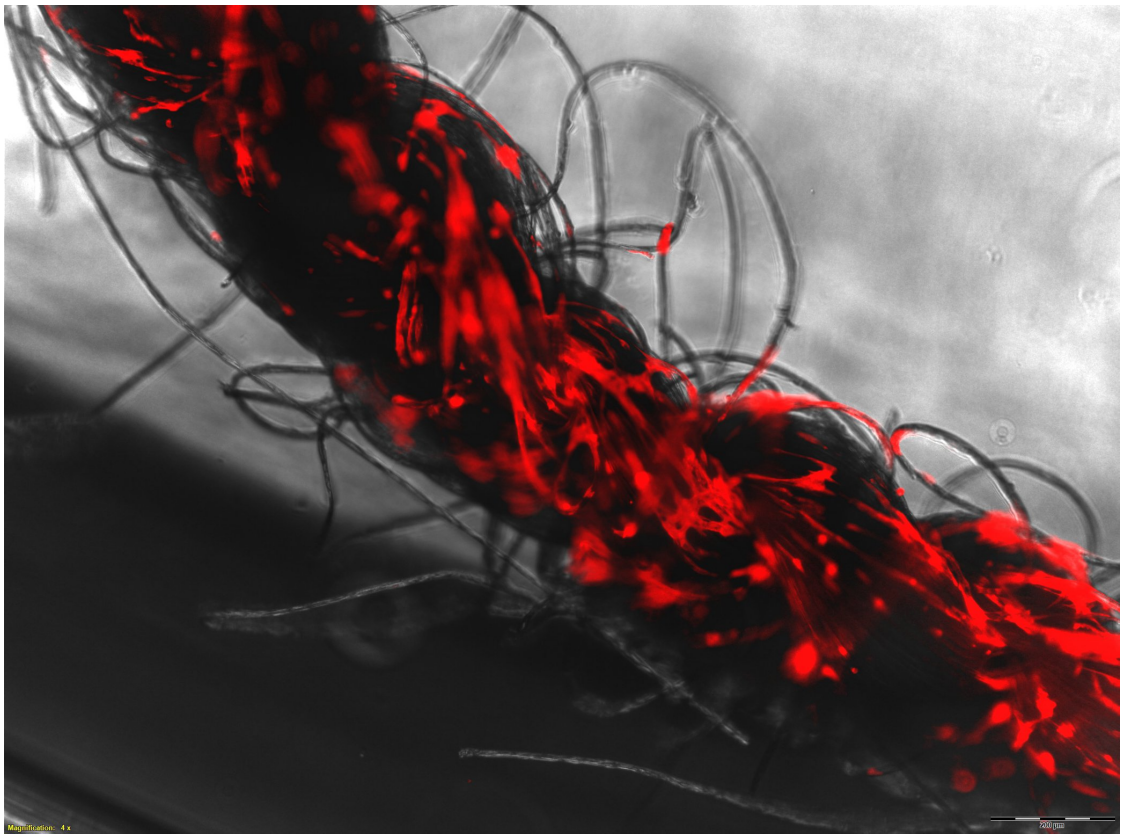


Figure 5.10

SeaCell™ three stranded braid, seeded with C2C12 cells, 5 days in culture, x4 magnification

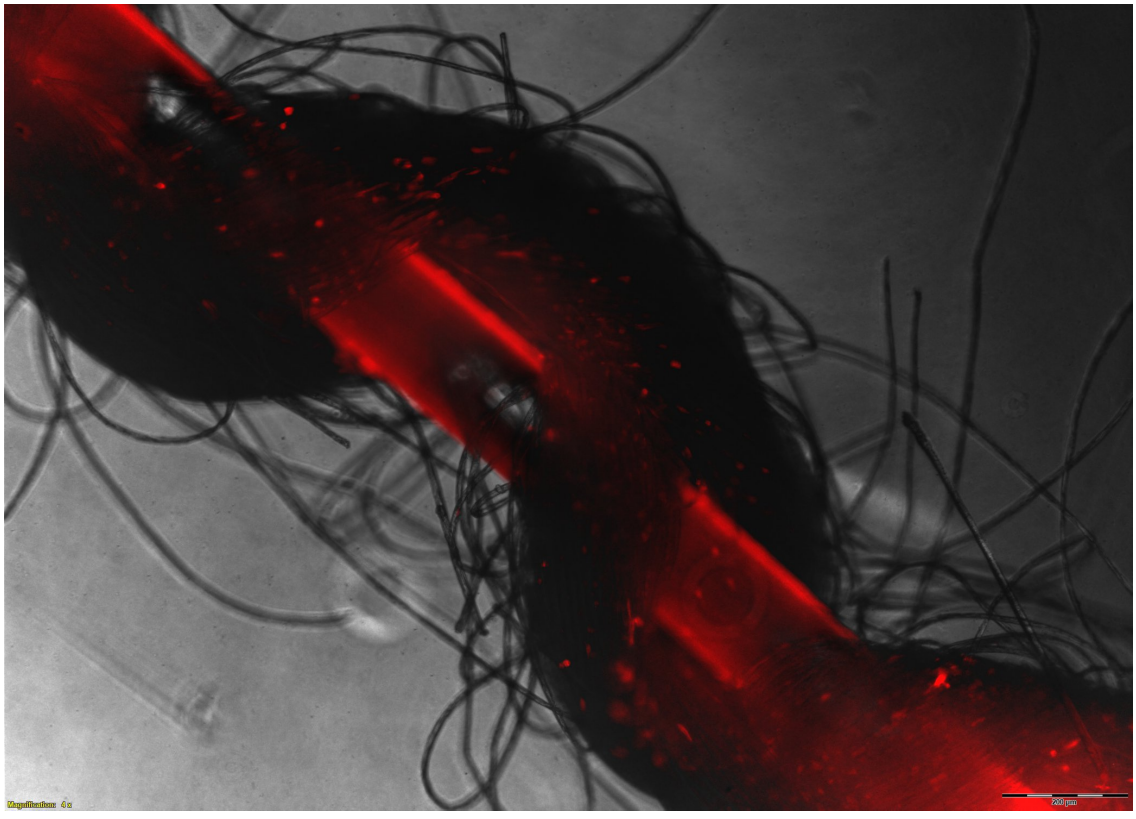


Figure 5.11

Three stranded braid; 2 strands SeaCell™ and one strand nylon monofilament, seeded with C2C12 cells, 24 hours in culture, x4 magnification

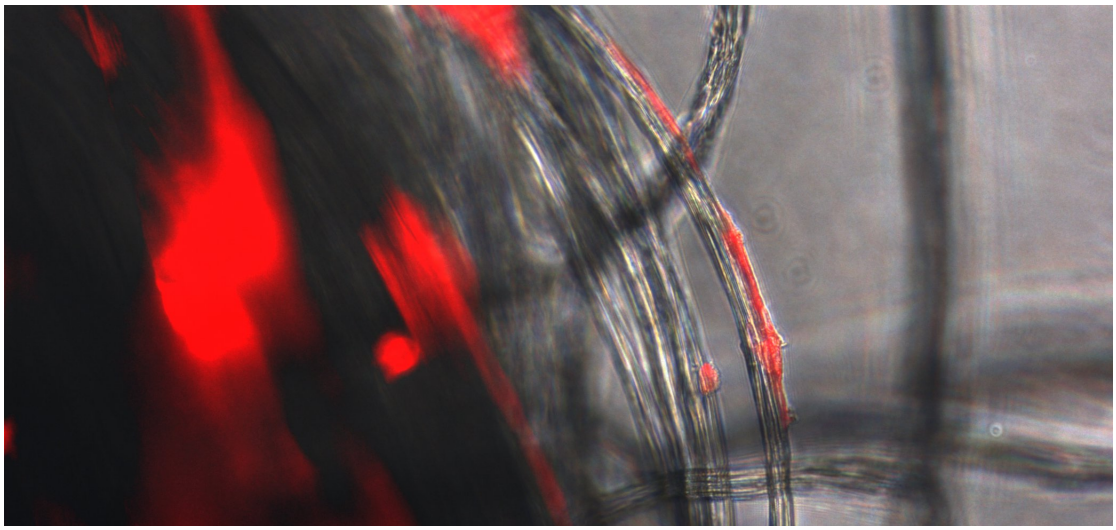


Figure 5.12

Individual cell aligning along single SeaCell™ fibre on three stranded braid scaffold.

Seeded with C2C12 cells, 5 days in culture, x20 magnification

5.5 Impact, Implications & Discussion

Directionality & specificity

Two of the most effective textile structures seeded in this series of experiments were french knots (figure 5.9) and three-stranded braids or 'plaits' (figure 5.10). Each showed cells attached and orienting themselves around the different structures. All cells, apart from blood vessels, are looking to attach themselves to something. Therefore, the essential goal with any scaffold is to make it more 'attractive' or conducive to cell attachment than the bottom of a culture dish. By nature, scaffolds need, at the very least, to encourage cells to adhere to them. The architecture that is created needs to be instructive to cells rather than prohibitive. So in addition to the basics of allowing cells to attach, another key property of a scaffold is to encourage directionality - to instruct cells to orient themselves in a certain manner. Demonstrating directionality is one of the reasons the majority of the scaffolds in these final experiments were seeded with C2C12 cells. For example, muscle cells, by nature, need to be oriented to take on a certain morphology. On both the three-stranded braid and french knot, the cells can be seen to follow the direction of the fibres and the pattern created by the arrangement of the fibres within the scaffold. This discovery is one of the key outcomes of the final laboratory work, which is inextricably linked to scale and its effect on cell orientation.

In addition to demonstrating cell orientation, the other key learning in the laboratory research was the impact of scale on orientation. The critical component for how scale had a significant

impact was the diameter of the fibres that made up the threads themselves. What became apparent when imaging the scaffolds was that the cells were attaching to, and aligning along, the individual fibres that made up the threads (figure 5.12). This alignment along specific sizes of structure is corroborated in other research papers. For example, the orientation of mouse fibroblast cells (L929 cells) on PLGA was studied and the results found that fibres between 10µm - 30µm were most successful and that on a fibre of a larger size (242µm) cells behave as if on a flat surface (Hwang et al., 2009, p.5) This correlates with the size of the individual SeaCell™ threads that measure in the region of 20µm. Whilst there have been studies exploring the effect of fibre diameter and surface topography on cell alignment, there appears to have been less done on how this can be utilised to construct scaffolds. This lack of translation is a clear gap where textile craft skills can be used to take this information and iterate. Once one understand how cells align themselves, and at what scale, it allows an understanding of what difference it makes whether one uses a ‘z' or an ‘s' twist thread, for example. At the beginning of this PhD, I was designing scaffolds using different structures - almost at the mm scale. This last body of research in the laboratory brought an understanding that a larger order structure, such as a weave or satin stitch, is secondary, and entirely dependant on the structure and orientation of the fibres that make up the threads that in turn make up the scaffold as a whole. It is this interdependent relationship, and the complexity of different levels of scale concerning a textile scaffold, which highlights the value a craft skill set can bring when developing highly bespoke scaffolds and being able to iterate upon results.

Another principle example of textile craft knowledge being successfully integrated as an approach to making scaffolds is the technique of ‘resist'. A process generally associated with dying fabrics; ‘Resist-dyeing is a widely used method of applying colours or patterns to fabric. A substance that is impervious to the dye blocks its access to certain areas of the fabric, while other parts are free to take up the dye colour.’ (Victoria and Albert Museum, n.d.). The concept was used to produce scaffolds that controlled where cells would and would not grow. This control was possible due to the knowledge of how different materials behave, generated through the material archive. Braids were created where one of the strands was made from nylon monofilament, as well as scaffolds with monofilament couched in place using SeaCell™ threads. Both showed cell growth on the SeaCell™ and none on the nylon (figure 5.11). This knowledge could easily be applied to creating scaffolds for regenerative medicine where there is often a need to stop cells growing in particular areas. It links to an essential concept in tissue engineering, which is bio selectivity - where one wants to be able to instruct, or know and control, where cells will attach. This control is particularly important, for example, in a scaffold

for a blood vessel where you want to have different types of cells lining the inside and the outside. It is also important to note here that the archive that has been developed should be viewed as a starting point. While I found that the cells I was using (HUVEC & C2C12), combined with the particular seeding technique, showed no attachment occurred on nylon monofilament, another researcher in the laboratory (Aran Batth) who was working with nylon monofilament did observe attachment with neural cells. This difference in behaviour demonstrates selectivity by cells to factors such as a different nylon monofilament, different cell type or seeding method. What this highlights is that the screening for bio selectivity needs to be an ongoing area of research to understand further intricacies; for example, which conditions cause which outcomes. This information can then be utilised to construct scaffolds able to instruct cells to attach in certain areas, as was demonstrated in the three-stranded braid scaffold or the SeaCell™ couched monofilament. This knowledge could conversely be used in future consumer product applications which rethink the manufacturing process. For example, it could be employed as a technique to selectively 'embellish' fabrics and trims in vitro. Where the base fabric does not support cell growth, but rather it is embroidered in certain areas with a material which is highly attractive to cells – creating 'zonally grown' embellishment. A visualisation of this concept can be seen in some of the informed speculations discussed in Chapter 6.

The knowledge generated in this part of the laboratory work has become the start of a craft system. This system has been enabled through working bottom-up, gaining an understanding of material behavior, and how different structures control cell growth. This information can be used and iterated on for different applications. For example, during my residency in the lab at Kings College London, I was asked to make some scaffolds for two different researchers. Firstly, a PhD student (Abi Glencross) who was researching aligning muscle fibres - C2C12 cells. I did repeat experiments seeding threads, both SeaCell™ and Milk, and passed on the protocol so she could replicate the experiment herself for comparison - both were successful. I then also made several trapped SeaCell™ fibre scaffolds for her to seed. The second researcher, I had the opportunity to interact with was another PhD student (Aran Batth) his research was focusing on aligning nerve cells - NG108-15 cells (neuroblastoma). Aran's research was experimenting with neuron alignment and growth. I created a number of trapped SeaCell™ fibre scaffolds for him also to test with his model (the same as the trapped thread scaffold in experiment 3 in the above table). Unfortunately, both collaborations were at very early stages as my research in the lab at Kings College London came to a close, and I was unable to obtain any images of results. However, they emphasize the importance of the approach and showcase

the value of having multidisciplinarity in the lab. One of the significant advantages of being a maker embedded within a laboratory is the ability to construct scaffolds whenever needed and to make adjustments in response to results, in order to develop structures for the next batch of experiments. This bespoke, responsive, and iterative process is not possible with commercial scaffolds or those that have been made by external parties.

Recording Results & Informing Others

During the period that I was working in the cell laboratory, it was apparent that my practice underwent a development influenced by scientific working methods. From previous experiences in laboratories, and as someone observing scientific practice, it is self-evident that the drive to produce and record data is significant - it engenders a culture of note-taking (Latour and Woolgar, 1986, p. 48). One of the first aspects I needed to navigate as a creative conducting experiments in a lab, was the documentation of this element of the practice. As with many people who suddenly find themselves in an unfamiliar environment, one of my first instincts was that I must record my work in the same way as the scientists with whom I was sharing the bench. My notebooks, and how I documented the experiments undertaken while at Kings, went through an evolution as I adapted the format to suit my practice. The recording of the work went through roughly three different guises. The first notebook I kept was excessive, I made notes and then studiously rewrote them in another book so that they would reflect what I thought a lab notebook should be. I rewrote my calculations and added extra notes on the addition of media (see figure 5.13) which was as much for myself as for anyone else reading them. As my comfort in the lab increased, my notebooks developed to be more of a hybrid between a traditional lab book and a sketchbook. I was combining notes on material measurements (see figure 5.14) in the same sketchbook that also held images of inspirational textile structures (see figure 5.15). Moreover, I was sketching diagrams for scaffolds in the back of the notebook I took into the lab to record results (see figure 5.16). This combination and synthesis of both types of note-taking became much more suited to the way I was working - foregrounding the significance of generating tacit craft knowledge as opposed to purely data. This hybrid approach ultimately influenced the third form of recording the work, the write-ups of the material archive and scaffolds (see appendices 3 and 4) that were designed to be legible to both a scientist and non-scientist.

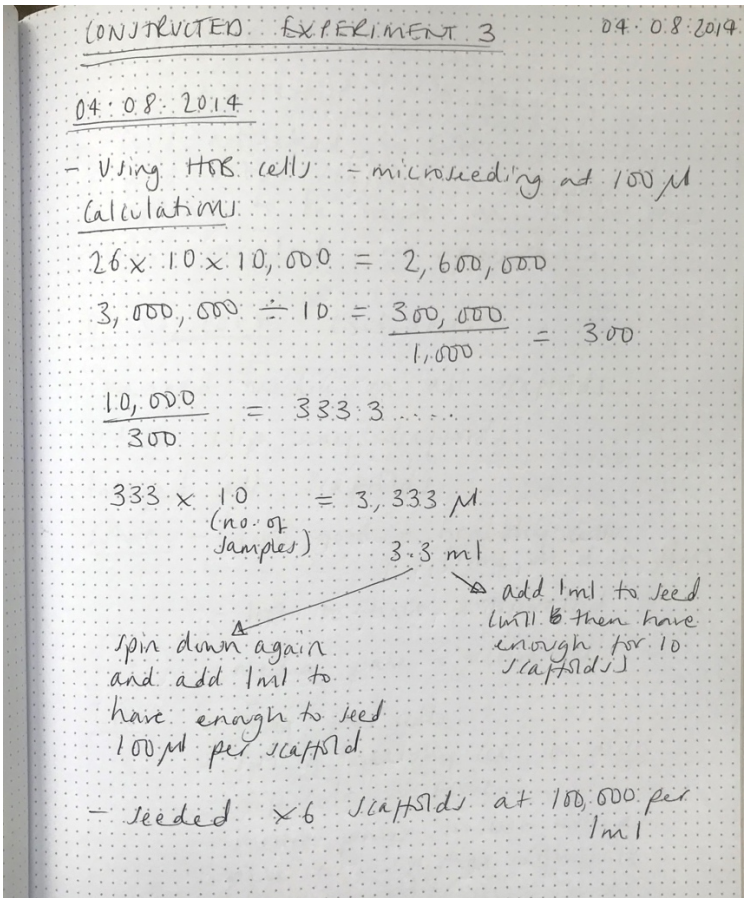


Figure 5.13

Rewritten lab notes in first lab notebook

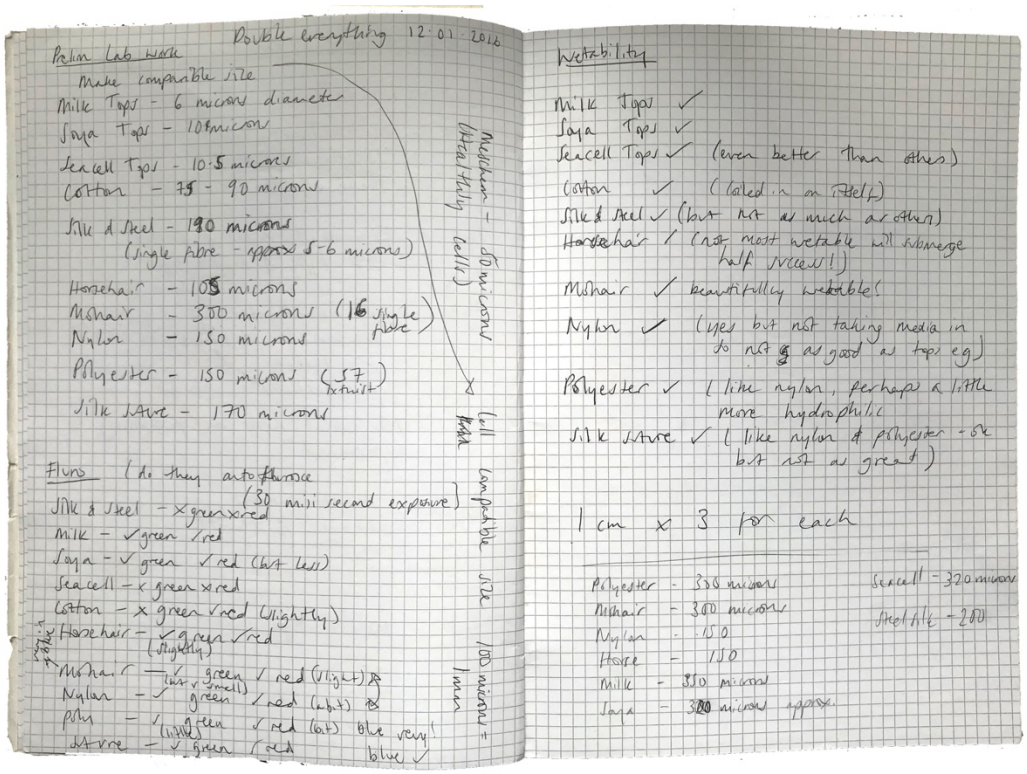


Figure 5.14

Material measurements in sketchbook

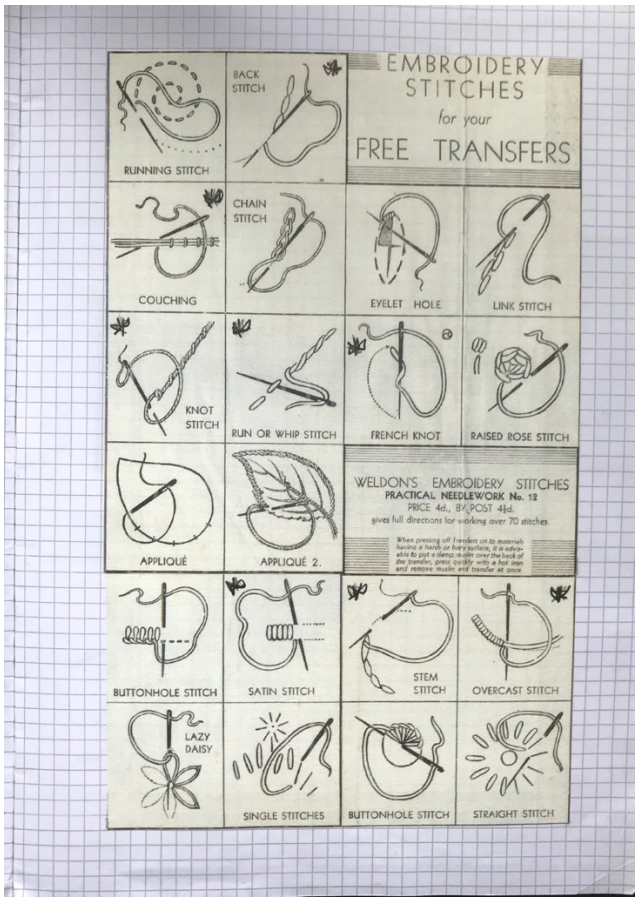


Figure 5.15

Textile structure diagrams in same sketchbook as figure 5.14

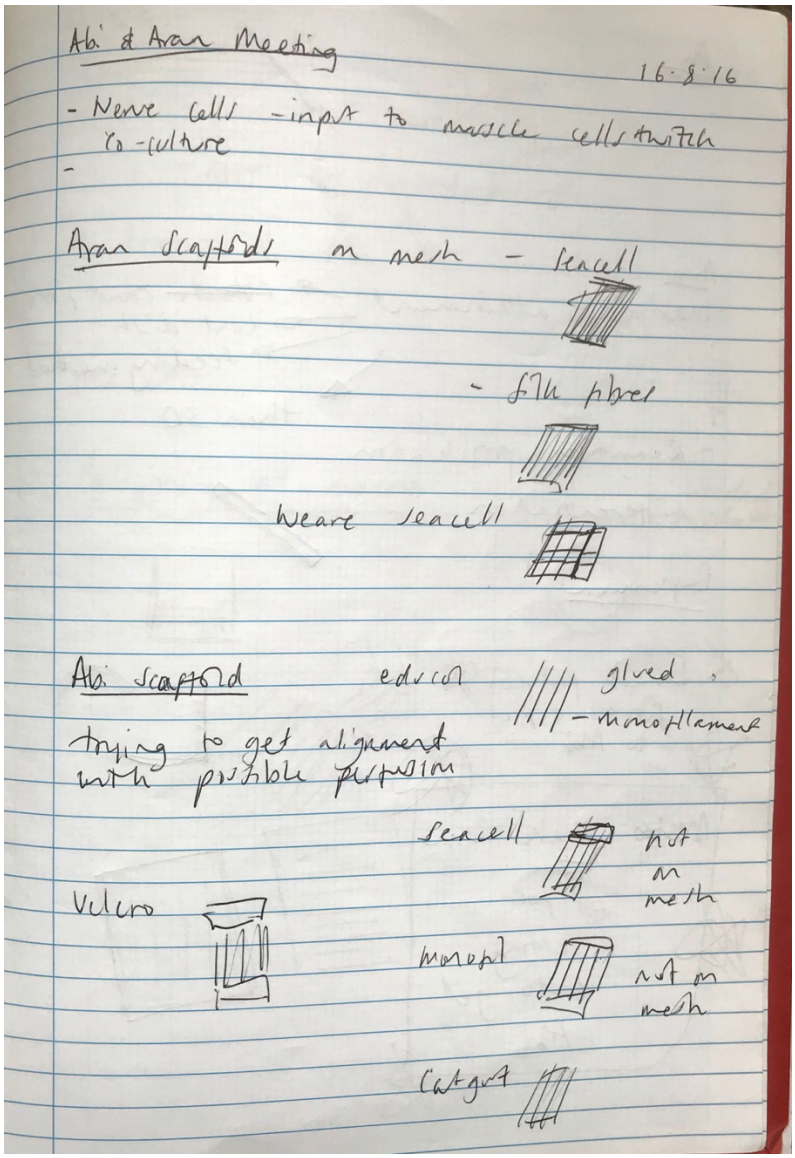


Figure 5.16

Scaffold structure sketches in lab notebook

The second mode of collecting information for the research was through pictures - captured by the imaging microscope within the laboratory. During the scaffold experiments there were some issues encountered regarding the imaging of each scaffold. As can be seen from the experiment tables in the previous section, it was not possible to get images of all scaffolds at every time point. The lack of a comprehensive set of imagery was due to several reasons. Firstly, the microscope in the lab was intermittently temperamental and, as a result, it was not possible to take images at every time point. Scaffolds not imaged at the time, along with those that were, were all retained to be imaged at a later date. The second issue that occurred was that of mounting the scaffolds, which involves securing the material to a glass slide in order to keep it indefinitely and prevent it from moving when imaged. No one in the lab had ever

mounted a three-dimensional textile scaffold before and so I developed a technique to try and secure them. Unfortunately, it was extremely challenging and not very successful - none of the samples were able to be imaged afterwards. Even though it was not possible to take images, notes were kept throughout the culturing of each scaffold. It is also important to highlight that microscopic imaging can be a selective process in and of itself. When you use the microscope you are taking extremely close-up images of only a fraction of the scaffold - therefore it is vital to understand you see only part of a bigger picture, quite literally in this case.

One of the main intentions of this PhD was to adapt a science-based practice to a design based one. Understandably there is an inherent difference in focus for a scientific PhD, which is dependant on data as a principal output, and a craft-based creative PhD, where a key goal is tacit/ material-led knowledge generation. Through the documentation of the lab work, both written, imaged and graphically represented (through the experiment write-ups in appendices 3 and 4), a holistic picture of the results was formulated. The work in the laboratory accomplished the goals of finding biocompatible materials and developing structures that showed cell attachment and orientation. Furthermore, I developed an understanding around which of the scaffolds were most successful, what structures yielded the best results, and how to alter them to change cell attachment and orientation. This knowledge developed through doing and observing, and evolved through my natural bias towards tacit knowledge as opposed to data. Even though a focus for the lab work was to develop an understanding of the materials and structures through working with them firsthand, protocols with replicable results were established which allow further work to be carried out in the future. Ultimately, what made the research successful for me is that it is a resource and body of learning that can be a starting point for others and future projects. To attest to this fact, the Tissue Engineering and Biophotonics group have expressed interest in setting the materials and protocols I developed as a brief/platform for their BSc student's lab-based coursework. As with any early-stage research, there would need to be further in-depth research and replication of results conducted to verify the findings for application in regenerative medicine. Finally, there has been keen interest in the research, which validates its findings and confirms the value of bringing a craft perspective into the laboratory.

5.6 Conclusion

This chapter began by presenting the approach taken in developing the material archive and subsequent scaffolds. The methodology used is outlined, presenting the iterative and emergent mode of working employed in the tissue engineering laboratory at Kings College London. Key to this way of working is the concept of 'top-down' vs 'bottom-up' in relation to tissue engineering and textile craft. Top-down is defined as being an approach to the creation of a product when the type of product desired is already outlined. This defining of the outcome is often the case within tissue engineering labs and research groups who have clearly defined areas of inquiry and almost always define what type of tissue they intend to recreate. What is then decided upon is selection of the most appropriate tools, materials and techniques with which to create said tissue or body part. Conversely 'bottom-up' is an approach where the end goal/ product is not identified at the beginning of the project. Instead, it is an exploratory way of working, where the results of each experiment help guide the development of the next. This approach is a much more amorphous way of working, which does have a marked relationship to craft practice - through the enquiry of material and processes. The results give a much more holistic view of the capabilities and characteristics of the material and how they may be potentially manipulated to obtain the desired outcome. This way of working has a great deal of freedom inherent. The latter is not always possible in tissue engineering research where funding and resources are tight. However, the results that have emerged from this approach have been valuable, and it therefore supports an argument to use this methodology more frequently within scientific research.

The chapter moves on to cover the creation of the Materials Archive. From the selection of thread types across the textile classification chart, with an emphasis on natural, more expensive materials. The development of a specific protocol for the experiments was presented, as well as the results. Several materials trialled appear never to have been researched within tissue engineering before, one of which: SeaCell™ , is highly biologically compatible and shows real promise. It is important to reiterate that the archive is in many ways, a starting point to be continually developed and expanded. Each different cell type, seeding protocol, and material type will yield different results. So, in many ways, this is the beginning of understanding and documenting the complexities of crafting with living materials.

One of the most exciting discoveries while conducting the Material Archive experiments was the importance of scale on cell orientation. Cells were aligning themselves along the individual

fibres, which made up the SeaCell™ threads. This knowledge was utilised in an iterative manner where different textile structures were created that explored this ability to control cell growth. Throughout the final laboratory projects, textile craft knowledge was infused into the approach, from the bespoke creation of different structures through to the utilisation of the idea of resist techniques to control cell attachment.

Finally, the chapter concluded by discussing the value and difference in recording data between the sciences and design. Whilst the textile designer's lab notebook in the tissue culture room may be a hybrid document, and images as results may not be the only measure of success, the main findings of the research include learnings in three key areas; scaffold scale, orientation, and bio-selectivity. Textile knowledge can use these as design parameters upon which to continually iterate and develop new scaffolds. A bottom-up approach, laying the groundwork to understand the materials and processes of tissue engineering textile knowledge, has the potential to be instrumental in the development of new scaffolds and techniques. All of which could have implications for both regenerative medicine and future consumer products.

CHAPTER 6:
Tissue Engineered Textiles: Current and Future Possibilities

6.1 Introduction

This final chapter presents a range of tools designed specifically for a textile designer working in a tissue-engineering laboratory. It also documents the creation of a range of 'informed speculations', produced throughout the laboratory work. These specific speculations were designed to communicate feasible future materials, and products, and are all directly informed by knowledge gained after hands-on work with the technology of tissue-engineering. In many ways, they brought the practice of the PhD full circle, but with the marked difference that the pieces were designed with a working understanding of the technology they are predicting. As conceptual prototypes, they were created to present the potential of the laboratory research to a broader audience and were conceived as vehicles to communicate what this could mean for our material and product futures.

The first project this chapter covers is the development of a range of tools; custom culture dishes[11] and tweezers. These were designed in direct response to the everyday tools of the laboratory and were intended to help rethink what these tools might need to be for a textile designer working in the space. To help focus the process of designing the tools, several fundamental potential products were reconceived, and previous problems, such as floating scaffolds, addressed.

The chapter then moves on to explore the new collection of informed prototypes which draw their designs and form from work conducted in the laboratory. These pieces were borne out of the tension between a design profession which is used to making things, and a technology where many of experiments conducted cannot be seen by the naked eye or touched by hand. They are material tests, not finished items, and so the question arose at multiple points during the research: how does one communicate work one cannot see? This need to present a section of the laboratory work dictated a need to develop further 'informed' speculative prototypes. How and why these prototypes are different is discussed in the middle section of the chapter.

[11] Usually a Petri dish is a name used to describe a glass dish, and a culture dish is made of plastic.

Moving on from one aspect of how the research was communicated more broadly, the chapter covers the development of the material archive. It also covers the production of a 'behind-the-scenes' film showcasing many of the studio and lab processes used. Additionally, it documents the creation of a collection of illustrations showing the most successful scaffolds. Finally, the chapter discusses one crucial final shift in the contextualisation and reading of the research as a whole. During much of the later laboratory research for this PhD, I had been describing the archive and subsequent scaffolds as a 'craft platform technology'. However, in revisiting reading from earlier in the research, I was reintroduced to the writings of Fritjof Capra and Pier Luigi Luisi and the 'Systems View of Life'. (Capra and Luisi, 2014). The terminology used is part of a more comprehensive range of vernacular applied to the life sciences; where programming and tech language is being used to describe biological processes. The problems with this were touched upon in Chapter 2 but are further discussed at the end of this chapter. In short, the most productive and complete way of framing the research is as a system and not a platform, a system which is interdependent, iterative and connected to a greater whole.

6.2 Laboratory Tools

> In fact, the practice of design — making things to serve a useful goal, making tools — predates the human race. Making tools is one of the attributes that made us human in the first place.
>
> (DiSalvo, 2015, p. IX)

In the process of working in the laboratory I was fascinated not only by the techniques and materials, but the available tools. During my time conducting experiments, I became intrigued by how tools were routinely used and how they could be adapted to suit the needs of a textile designer better. While the items I was using are readily available and were developed for their purpose, I found myself wanting to redesign them for my specific purposes. Just as a scientific revolution can be brought about by a piece of machinery not working (Kuhn, 1962, p. 5-6) then craft's traditional tools and processes have, in my practice, been forced through a process of reinvention in order to deal with the challenges of working in the laboratory.

The production of tools, as the opening quote suggests, can be argued as being one of the characteristics that make us human. We have been fashioning them for millennia, with the first stone tools dating back to 2.4 million years: found objects were selected and altered to be suited to a specific task. (Choi, 2009). We have been designing and evolving tools for every aspect of life ever since. A key example of designing tools fit for purpose in this field comes

from an early pioneer of tissue-engineering in the form of the Carrel D-Flask (Figures 6.1 & 6.2). ‘After working for some time, Carrel introduced a new form of culture vessel of his own design. This vessel, later known as the Carrel flask, was widely used well into the 1950s. It was a small, flat, round flask five or eight centimetres in diameter, with a narrow, oblique neck.’ (Landecker, 2007, p. 82) This example highlights the potential of the inventive skill of a maker who truly understood the material with which he was working. It epitomises the ‘reified theory’ notion introduced by Bachelard who argued that ‘the role of instruments was to help "concretize the abstract", as only instruments could "realise" the possibilities produced by a scientific theory.’ (Hessenbruch, 2013, p. 377)

Figure 6.1

Carrel Flask

(Carrel, n.d.)

Figure 6.2

Carrel Flask (Rockefeller Archive Center, n.d.)

Craft theorist Glenn Adamson terms the process of making instruments ‘tooling’, and it ‘can be defined as the making of objects that go on to make other objects. It is best understood as an

ongoing process - not the supply of actual physical tools, lying ready to hand, but rather the whole system by which an infrastructure of making is brought into being and subsequently transformed to suit various tasks.' (2013, p.31). Thinking on ideas of systems is how a new series of tools developed as a product of the PhD practice in the laboratory. When considering what would be needed to grow a piece of fashion, different processes used in the métiers of haute couture were reimagined. It involved not only the design of specific items but a rethinking of the system of manufacture. How would we design and manufacture our future fashion if new technologies release us from previous modes of production?

One of the most common types of tools used in a tissue culture laboratory is the culture dish. Whether they are found individually or as a 6 or 96 well plate, the culture spaces are nearly always round. This shape works perfectly well for the culturing of most cells and the completion of most experiments. However, as discussed in Chapter 4, some of the research's first scaffolds floated and were subsequently redesigned to be round and therefore fit the culture well. In making new tools, the aim was to redesign the culture dish for the scaffold, not the other way around. Several key issues and activities were reconceived and had new dishes made for them, as well as a new pair of tweezers - another standard piece of equipment in the lab. The intention for the new dishes was to have them made in glass, and subsequently, much time was spent looking for manufacturers who could make the new designs. Though it was technically possible to create the dishes, the process that would need to be used was hugely cost-prohibitive - to the point where an order in the magnitude of 1,000 pieces would need to be commissioned. This realisation prompted the choice of a different production method; 3D printing.

Culture dish 1: In vitro flower

The first piece reimagined was the creation of an artificial flower, the kind which would typically be produced in parurier floral métiers (see figure 6.3). Using the flower as a starting point, two dishes were designed with wells the exact shape and size of the petals. The current mode of production for these is to take pieces of fabric and punch/ cut out the petal shapes. However, why waste any material in cutting out if it can be grown to shape (see figure 6.4 - 6.6). Two different dishes were created to accommodate the growth of the different sized petals needed to make the flower. The flower in that image is an informed speculative prototype, not one that has been grown. The reason behind creating a speculative prototype is discussed further

on in this section, and the notion of informed speculation is covered in a later part of this chapter.

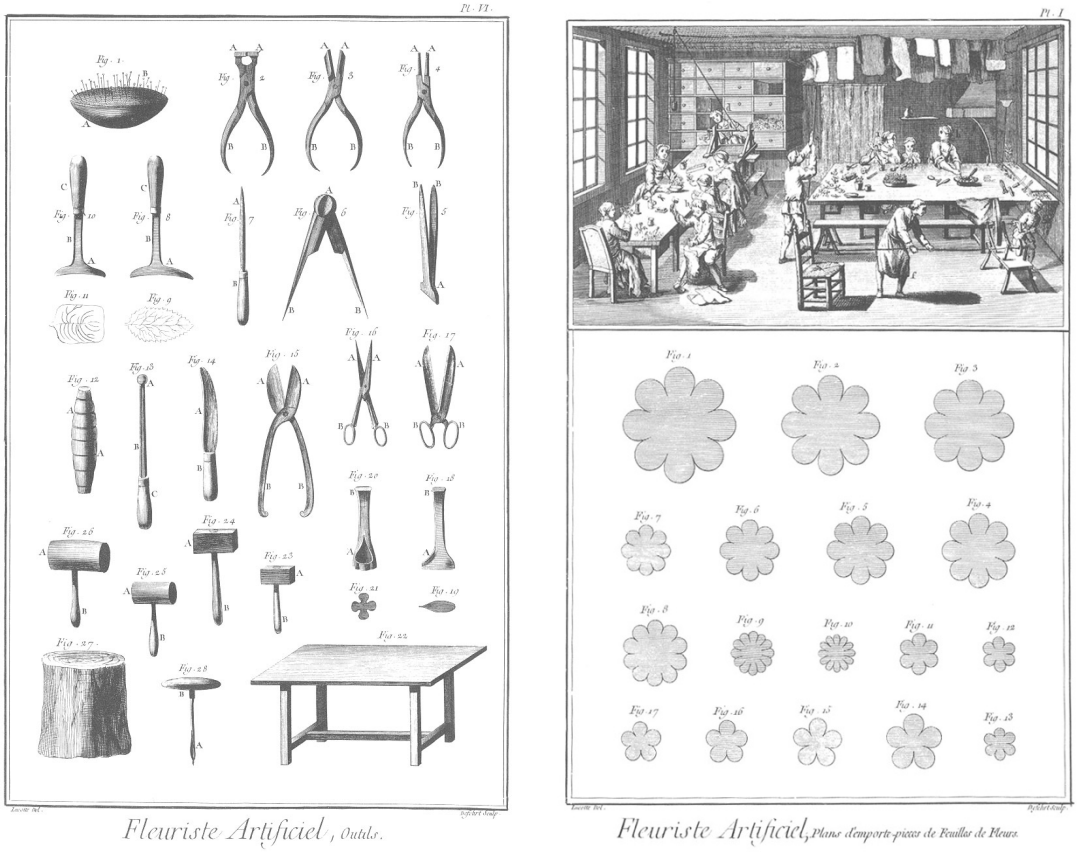


Figure 6.3
Fleuriste artificiel. From Encyclopédie ou Dictionnaire raisonné des sciences, des arts et des métiers (University of Michigan Library, 2010)

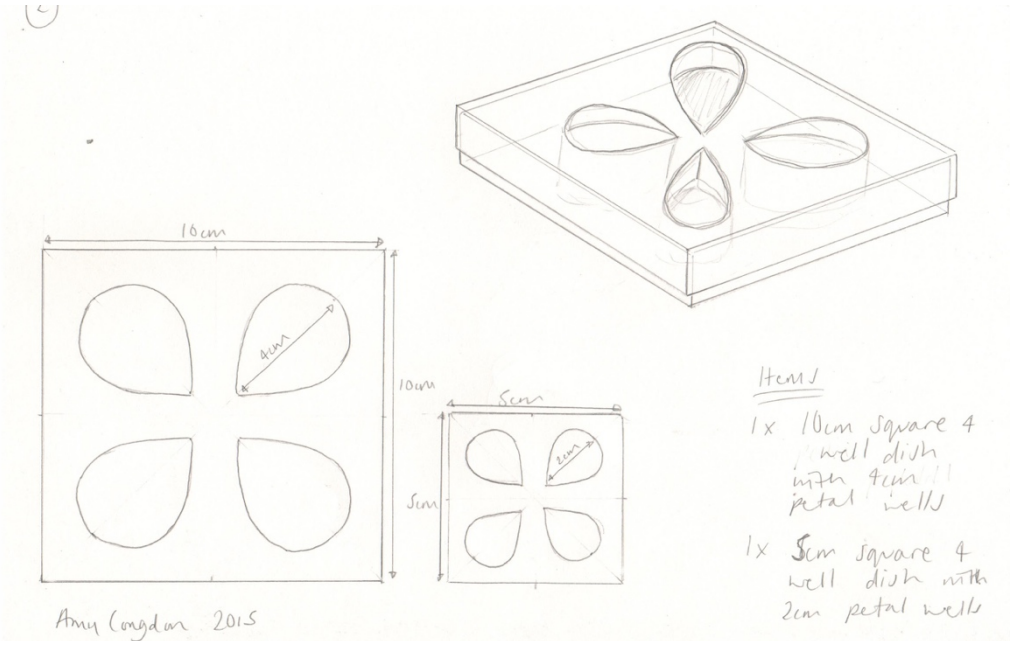


Figure 6.4
Sketch design for 'In Vitro Flower' Culture Dish

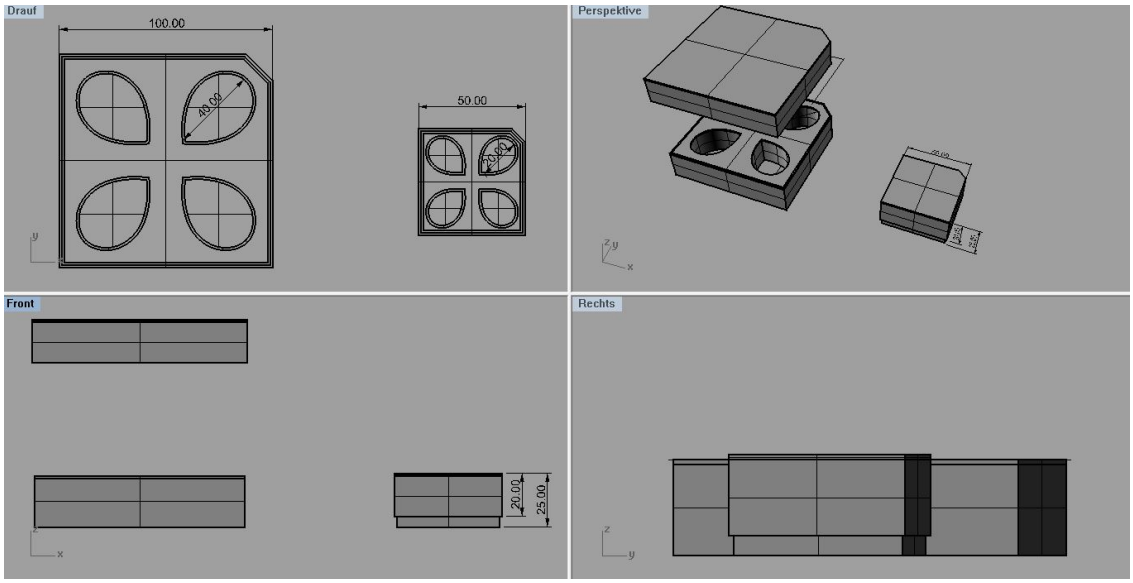


Figure 6.5

Screenshot of 3D models (created by Anne May Abel), showing the shape of the culture dish. I added an update to the design, cutting the corner off so that when used the lid would be put back in precisely the same place (and prevent cross-contamination between wells)

Figure 6.6

This image shows a speculative prototype of what a flower grown in the culture dish may look like, sitting in front of the finished 3D printed dish.

Culture dish 2: Tissue culture hoop

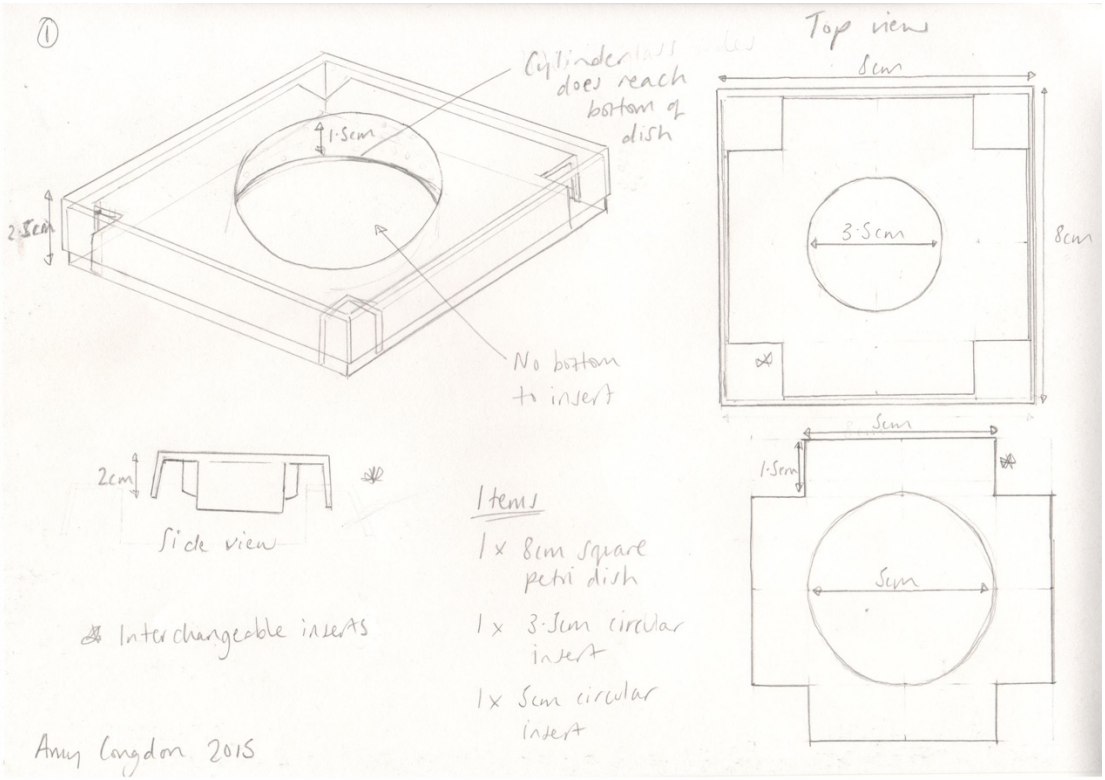


Figure 6.7

Sketch design for 'tissue culture hoop' Culture Dish

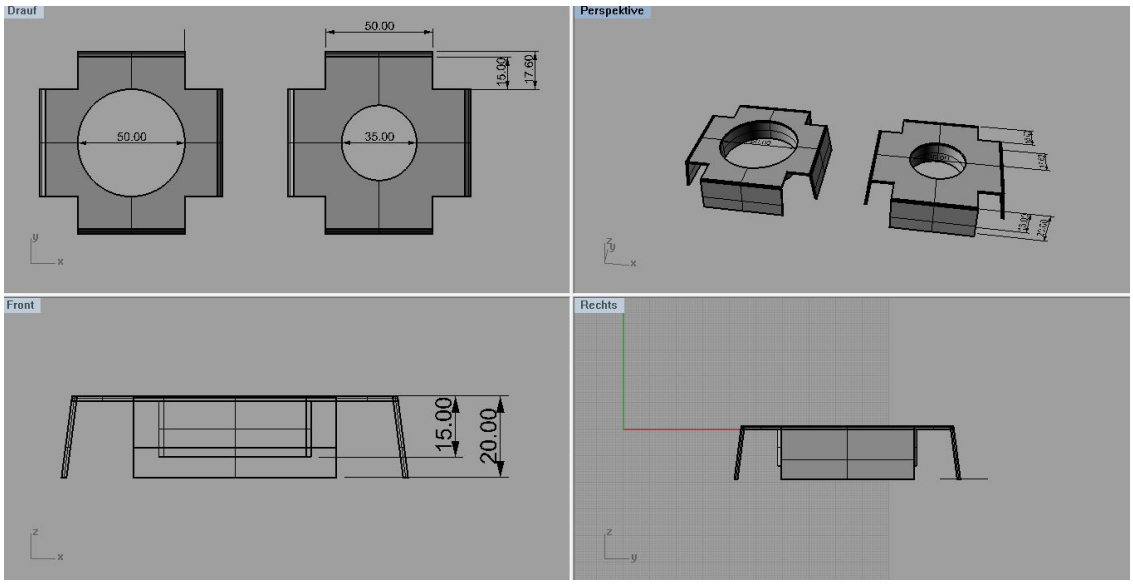


Figure 6.8

Screenshot of 3D models (created by Anne May Abel), showing shape of culture dish.

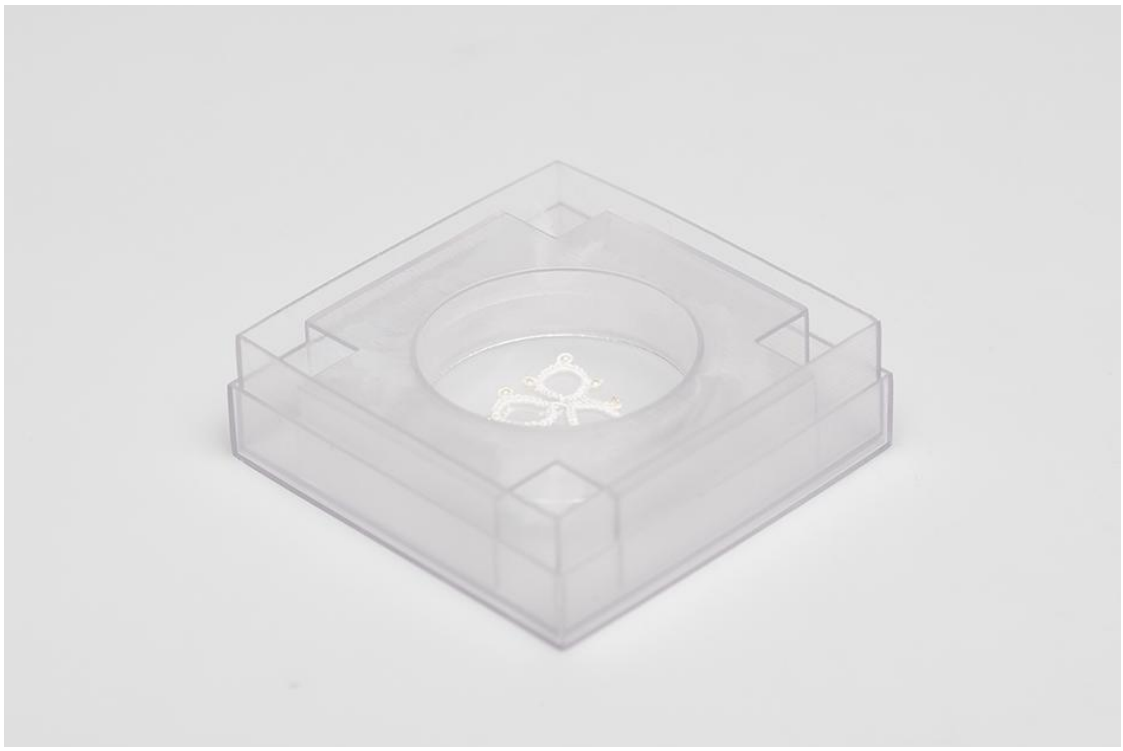


Figure 6.9

Image of the finished 3D printed culture dish and insert

Figure 6.10

This image shows the 3D printed square culture dish, from figure 6.9, in use - securing a scaffold so that it doesn't float or move whilst in culture

The second dish focused on the problem encountered in the initial experiments (Chapter 4) where the scaffolds floated within the culture plates. To mitigate the issue of floating, a traditional tool used in textiles was incorporated into the design. An embroidery hoop was redesigned with influence from existing scientific items such as cell strainers (see figures 6.8, 6.9 & 6.10). The set-up includes one outer dish, which was square, and an insert that has a tube in the middle that does touch the bottom of the dish and stands on four wide legs. The design of this insert was to allow the securing of a scaffold, or piece of material, with a hoop (figure 6.10), which was laser cut from acrylic, whilst also enabling media to be added or changed without disturbing the scaffold in culture. Finally, it was important for the scaffold not to touch the bottom to know that all cells growing on the scaffold were indeed attached, and any that were not would fall to the base of the dish.

Culture dish 3: In vitro embellishment

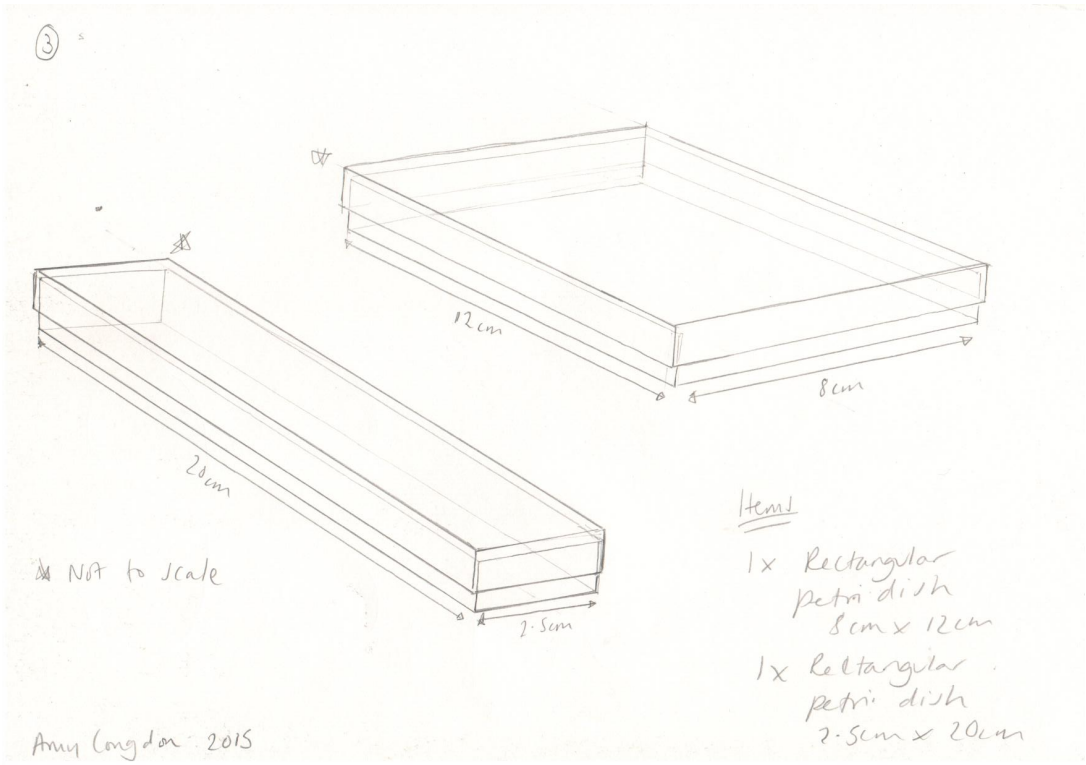


Figure 6.11

Sketch design for the 'in vitro embellishment' Culture Dish

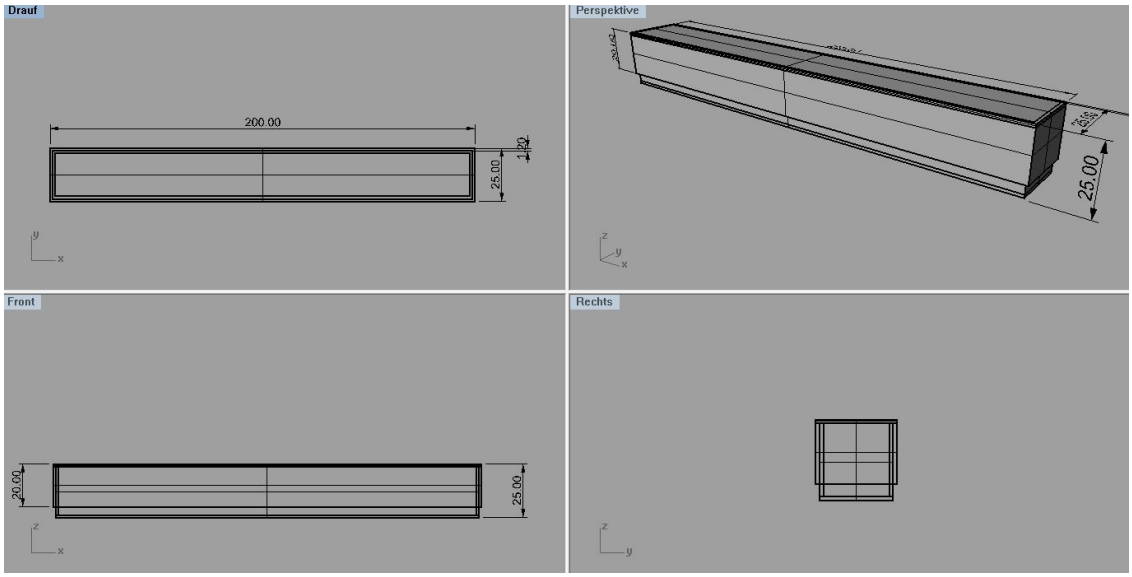


Figure 6.12

Screenshot of 3D models (created by Anne May Abel), showing shape of culture dish.

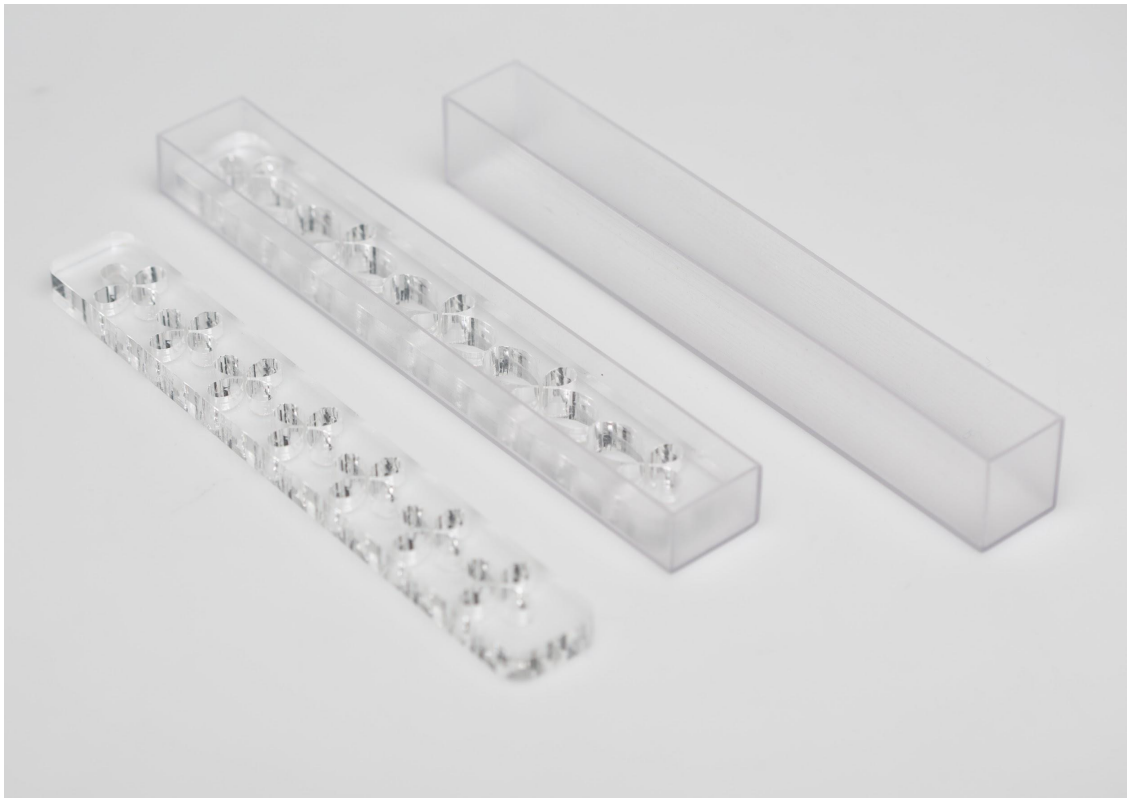


Figure 6.13

Photograph of finished 3D printed culture dish, shown with laser cut acrylic weights - designed to hold down fabrics during culture and with wells to control cell growth

The final culture dish created was a long rectangular dish (see figures 6.11, 6.12 & 6.13) which was designed to hold ribbons that could be embellished in vitro. The dish also had corresponding weights which have the dual purpose of holding the fabric down and also creating wells for localised concentrations of cells. The weights in figure 6.13 were made from laser-cut clear acrylic to allow the maker to see the colour of the media and thus notice if a media change was need. The inserts can also be interchangeable, allowing for any number of designs to be achieved within this one dish. Specifically, this dish was intended to rethink the process of applique, proposing the possibility of growing an embellishment directly onto a fabric or ribbon - for example, bone polka dots.

Textile tweezers

Finally, a set of tweezers were designed, based on existing models (see figure 6.14), but adapted for a textile designer's use. Tweezers are commonplace in the tissue culture laboratory and invaluable, as when working in a sterile set-up you cannot touch the materials you are dealing with; they become an extension of your hands. To further complicate matters, when unable to work directly with your hands often the materials or scaffolds you are working with are small and difficult to see. Tweezers of this nature do exist, but in this design, the magnifying glass on the handle was positioned on a different side of the tweezers to reflect the fact that items being picked up, namely textiles, were most often flat, in contrast to items customarily handled in the laboratory.

Figure 6.14

This image shows the tweezers I designed specifically for a textile designer's use in the tissue-engineering laboratory (the design realised by jeweller Anne May Abel). They are designed to hold flat fabric scaffolds under the magnifying glass attachment for closer inspection.

As discussed at the beginning of this section, the intention was for the tools to be produced for use in the laboratory. However, after much research, and many discussions with manufacturers, it proved impossible to get glass Petri dishes made with square corners - unless I could finance large production runs. Therefore, the final pieces were 3D printed using transparent plastic, which, unfortunately, could not be sterilised for use in the lab. While it was incredibly disappointing that the dishes and tools could not be used in the laboratory, it was of the utmost importance to respect and protect the work of the other researchers in the lab that would have been severely affected by any contamination caused. Even though there was not the opportunity to use them, the pieces were still significant in how they helped the thinking around how we might make products in the laboratory and highlighted the result of incorporating textile craft expertise to overcome problems. Overall, the resulting prototypes helped to "concretize the abstract" (Hessenbruch, 2013, p. 377) and serve as tangible examples of what growing materials in the laboratory means for tools and systems of production.

6.3 Informed Speculations

The concept of making ideas concrete, in order to communicate them more effectively, was one of the main driving forces at the beginning of the research and why speculative design was employed as a method. However, as discussed in Chapter 3, this approach began to feel limited, and the research naturally shifted from exploring the implications of growing materials in the laboratory, to working with the technologies in question to understand how that might be achieved. Nonetheless, throughout the PhD, there have been several invitations to exhibit the work. This type of request was not always straightforward to accommodate, as the majority of the work conducted in the laboratory does not consist of finished objects. Therefore, the question was how to communicate the research and its potential. To address this issue, the methodology employed in the speculative design projects was adapted at various instances throughout the PhD, with the main difference being that all the prototypes produced were based on a firsthand working understanding of current technology. The creation of ‘informed probes' was born out of a necessity to communicate the laboratory research and to make its potential accessible to a non-specialist audience. With that in mind, the practice has at points come almost full circle, with some notable exceptions. What the previous statement is referencing is that the conceptual prototypes were made in response to the research in the laboratory.

The prototypes in question were created to answer the need to effectively communicate the implications and potential applications of the work being carried out in the laboratory to a broader audience. Three key examples of exhibitions, for which new work was created, are Biofabricate 2014 & 2015 (Microsoft Headquarters, New York), Utopia (2016, Somerset House, London) and *Biological Atelier: The Showroom* (2016, Manchester Craft & Design Centre, solo exhibition). For example, at Biofabricate 2015, the new tools were presented alongside a selection of 'grown' flowers and trims. They had not been created in the laboratory, but they visualised what could be achieved as the research progresses. They were speculative design objects, firmly grounded in a working knowledge of the technology. This is a notable exception to the early speculative work, which was created from the outside looking in rather than from the inside trying to communicate outwards.

Other speculative prototypes created during the research include '*Leather Lace*' (figure 6.17), bone and pearl trims, a '*Biological Performance Shoe*' (figure 6.18) and '*Biologically Embellished Fabrics*' (figure 6.19). Each of the items in the figures listed have been exhibited, with other flowers/ trims added as necessary. They all circulate the central idea of haute couture and how biotechnology has the potential to change its material palette and utilise its craft processes in new ways. What formed a concrete bridge in every exhibition mentioned above, between these mocked up products and the research taking place in the laboratory, was the inclusion of a materials archive (figure 6.20). This archive took the form of a range of materials, housed in Petri dishes, sitting next to a microscopic image of cells growing in culture, on those materials. The vast majority of the images shown came from the initial work in the laboratory, and it was the realisation of how important a resource it was that prompted the development of the more comprehensive archive presented in Chapter 5.

One recurring theme throughout exhibitions was how to contextualise the work and communicate it to the audience. Two prominent examples of this are the *Biological Atelier: the showroom* (figure 6.21) and *Utopia* (figure 6.15) exhibitions. Both shows played off the concept of presenting the work as though the visitor is walking into a couture maison (house). For *Biological Atelier: the showroom,* a variety of projects were brought together to present this vision, from early speculative work including the '*A.C. Skincare Range*' through to a new film developed specifically for the show. The video is covered in more detail later in this chapter.

In ‘Utopia', an essential communication tool was a specially designed website (www.t-e-atelier.studio) that accompanied the physical objects on display. The balance of the content for the website was crucial. The aim was to both suspend disbelief, asking site users to ‘shop' for their future grown couture, while also introducing the project background and the ongoing research in the laboratory. One of the central roles for the ‘shop' section of the site was to gather anonymous feedback from users on different aspects, such as would they order something from an extinct animal cell line or even their own cells. The language for how this was put to people was also important, in particular referencing ethics (figure 6.16) and the possible role of legislation in the creation of future products such as these.

One of the reasons the practice moved away from speculative design work was that it felt limiting to hypothesise about the potential of a technology without ever having worked with it. In making that statement, I will be the first to admit that it may well stem from a craftsperson perspective, i.e. to understand something I have to have hands-on experience of it. There are additional concerns levied at work developed out of a relationship with a scientist. During a panel discussion I participated in, there was a discussion around critical distance, and the question asked was along the lines of "are designers or the work compromised by worrying about offending the person or institution they have worked with"? While I would subscribe to the view that it is imperative to question partiality and take into account the context within which work is done, the speculative prototypes made in the later stages of the PhD practice were intentionally made whilst I was embedded in a scientific environment. Finally, this also links to a decision made when making the ‘behind-the-scenes’ film, where no end product was revealed, and some have commented that it left them wanting. Perhaps this is where I have become compromised by working with scientists, but there was a conscious choice not to want to be in any way disingenuous and suggest that a mocked-up prototype had been grown through the process shown in the film. The work discussed here, for me, manifests ideas based on a knowledge of the technology and have a pertinence precisely because of that. They are plausible, or even probable futures, and there is an urgency to communicate and discuss them.

One of the most keenly felt tensions for designers working within the discipline of critical or speculative design is that of feeling complicit in some way, that the work produced can be reframed to support the very technology being questioned. That if a scientist has opened up their laboratory for you, and shared their research, it can feel ‘wrong, almost treacherous, to pick up on negative possibilities.’ (Dunne and Raby, 2013, p. 54). To avoid this scenario, Dunne

and Raby discuss other artists and designers who take a different approach, which is to "work independently with scientists as advisors rather than creative partners." (2013, p. 54). However difficult it can be to feel free to voice concern when embedded within the development of a technology, not working in a laboratory and being distant from the realities that presents, has always felt a little to me like throwing 'problem grenades' from the sidelines — waiting to see how they land and the ripples they cause. This statement is not to say it cannot be done well, or that I disagree it can be hard when operating within certain situations, but my main concern is that this type of work not become critique for critique's sake. I think in many ways to be a designer is to be implicated, to be in the thick of it - therefore while critique is vital, for me it must be combined with some suggestions on how to move forward in some real and constructive sense. 'If we are going to commit to being part of such experimental collaborations, we may also have to think of ourselves more explicitly as "participants" rather than "spectators" (Barad, 2007) in technoscientific worlds, because it is only if we participate that we can create something new together – whether this be knowledge, practices or things. We may have to admit our complicity and become part of the fields we study. We will lose distance, but we may gain something more unexpected.' (Calvert and Schyfter, 2016, p. 212)

This feeling is reflected in the preoccupation of curators such as Paola Antonelli and has become the remit of upcoming exhibitions, for example, 'Broken Nature'. The show, which opened in March 2019, comes almost a decade after the seminal 'Design and the Elastic Mind' (an exhibition held at the Museum of Modern Art in New York). The description suggests a shift from a focus on critical/ speculative design, much of which was featured in the Design and the Elastic Mind exhibition, to one where designers are asked to offer solutions rather than merely problems; 'In exploring architecture and design objects and concepts at all scales and in all materials, Broken Nature celebrates design's ability to offer powerful insight into the key issues of our age, moving beyond pious deference and inconclusive anxiety. By turning its attention to human existence and persistence, the XXII Triennale will promote the importance of creative practices in surveying our species' bonds with the complex systems in the world, and designing reparations when necessary, through objects, concepts, and new systems.' (Antonelli, 2018)

The trajectory of this PhD has been one that has walked a line between Speculative and application-based work. Whether this is a balance possible to strike is discussed by Oron Catts concerning his involvement in the Synthetic Aesthetics project; '"Very few professions actually are allowed to spend their time engaging in developing something only for it to be contested.

Designers and engineers are trained to find solutions that are going to bring closure in a sense; they're not interested as much in the idea that what you're engaging with is designed to be questioned." (OC interview Perth)' (Calvert and Schyfter, 2016, p. 202). This statement is true in many situations but is something that should change as we become increasingly aware of the social, cultural and most importantly, environmental impacts of what we make as designers. It seems increasingly inconceivable to not be cognizant of the impact what you make can have. What I would argue for is a path between that of critique and solution-based work especially when working with new technologies - design that is aware of its potential impact but striving towards new solutions that takes this into account. As Oron Catts put it '"[t]he artists who are involved with it are implicated within the whole process; they can't take a distanced stance, they actually have to engage, they can't be self-righteous about it." (OC interview Perth)' (Calvert and Schyfter, 2016, p. 208).

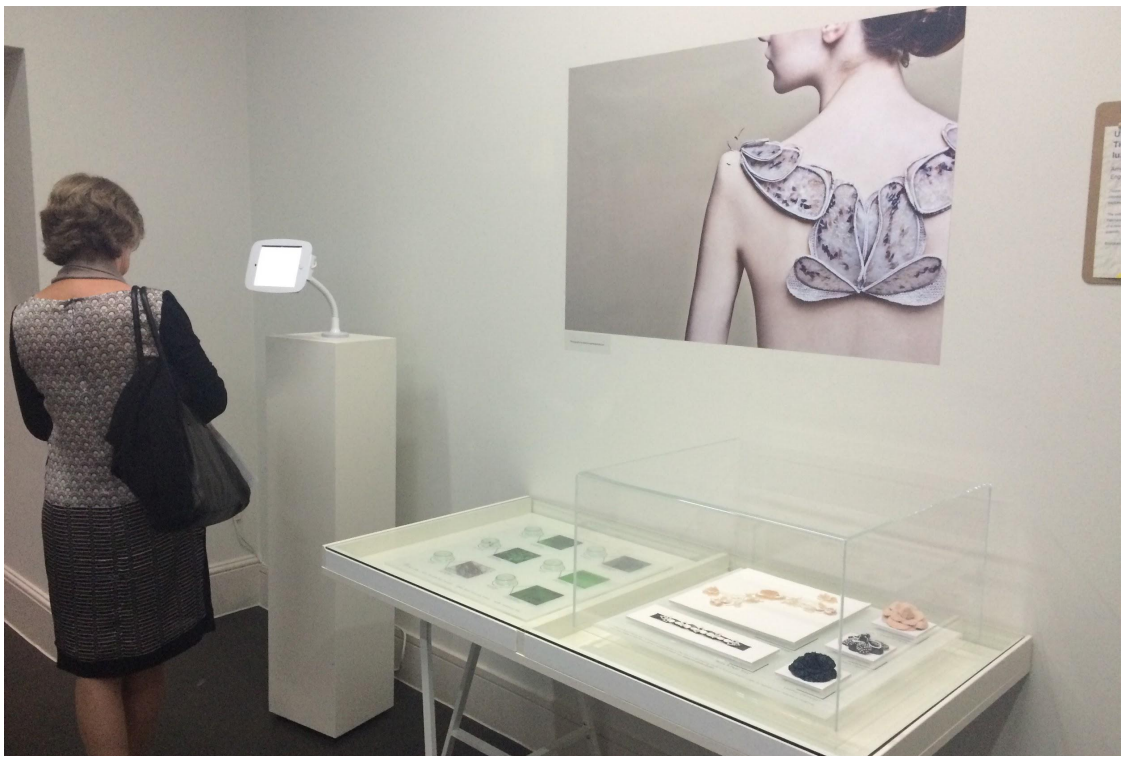


Figure 6.15

'Utopia' exhibition, 2016, Somerset House, London, UK

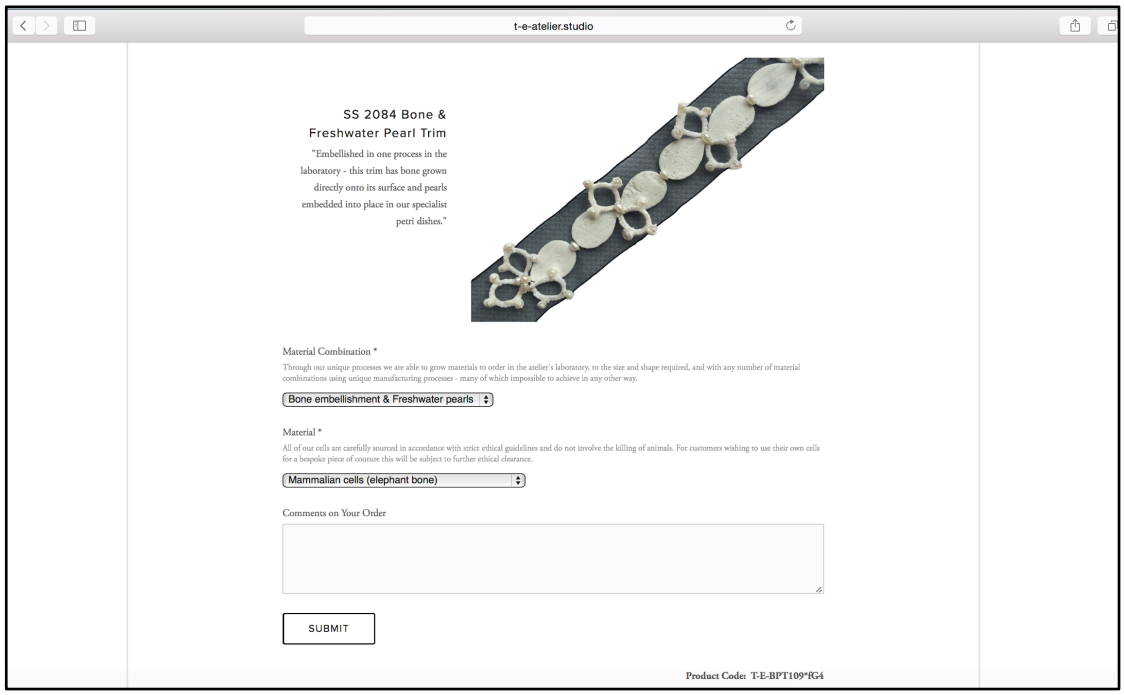


Figure 6.16

Screenshot from the website I designed to accompany the 'Utopia' exhibition pieces www.t-e-atelier.studio

Figure 6.17

‘LUXURY LEATHER LACE: What if we could grow beautiful transparent leather in the laboratory, over embroidered silk threads to create high-end couture pieces. With added embellishment coming from freshwater pearls set into place by bone grown around them in one process.’ (Congdon, 2014c)

Figure 6.18

‘BIOLOGICAL PERFORMANCE SHOE: What if we could grow high-performance leather to order; in the shape, thickness and surface finish required. All elements of the shoe could be grown and integrated in the laboratory itself, with high-performance fibres added to give structure and stability where needed.' (Congdon, 2014c)

Figure 6.19

'BIOLOGICALLY EMBELLISHED FABRICS: What if we could grow pattern and embellishment directly onto fabrics in one process. Imagine bone polka dots, unique hybrid leathers with any surface finish desired and even bone & leather spots - all produced within the petri dish.' (Congdon, 2014c)

Figure 6.20

Initial material archive and 'informed speculations' on exhibit at Biofabricate 2014 Summit

Figure 6.21

'Biological Atelier; the showroom', 2016 solo exhibition at Manchester Craft and Design Centre, UK.

6.4 Communicating the Work

How to communicate the work conducted during this body of research has always been a central question. It has driven the practice in the laboratory when speculation felt like it was inadequate; it created further prototypes when the laboratory work was not enough on its own. It has also been the instigation for a materials archive and range of scaffold illustrations. All to disseminate the research and explain its potential impact.

As touched upon in other parts of this chapter, there is an inherent problem when working with a technology like tissue-engineering and showing results, especially when conducting material research in the lab. The aim in all the experiments conducted was never to make a finished piece, but instead, it was to test a hypothesis, e.g. will cells grow and proliferate on this material or scaffold. The pieces could have been kept in culture longer, but this would not have allowed for iteration or numerous experiments. This approach provides results to be viewed and assessed, but it does not mean those results will be easily digestible by those who are unfamiliar with the technology. It was due to these factors that a range of outcomes were developed. These outcomes are distinct from the informed speculations discussed above in that they focus solely on communicating real experiments, and processes, conducted during the research.

The first outcome, touched upon in a previous section of this chapter, is the film made for the *Biological Atelier: The Showroom*. The video is a 'behind the scenes' style video, beautifully shot and edited by Ann-Kristin Abel. The film details the creation of different textile scaffolds and follows them into the lab for seeding and incubation. There were very intentional references made, in the style and tone of the film, to existing behind the scenes looks at haute couture collections, most notably those of Chanel. As a piece, it was intended to draw parallels between the current 'Metiers d'arts' and 'petite mains', and how these might shift in skill and focus with the potential advent of biotechnology being introduced.

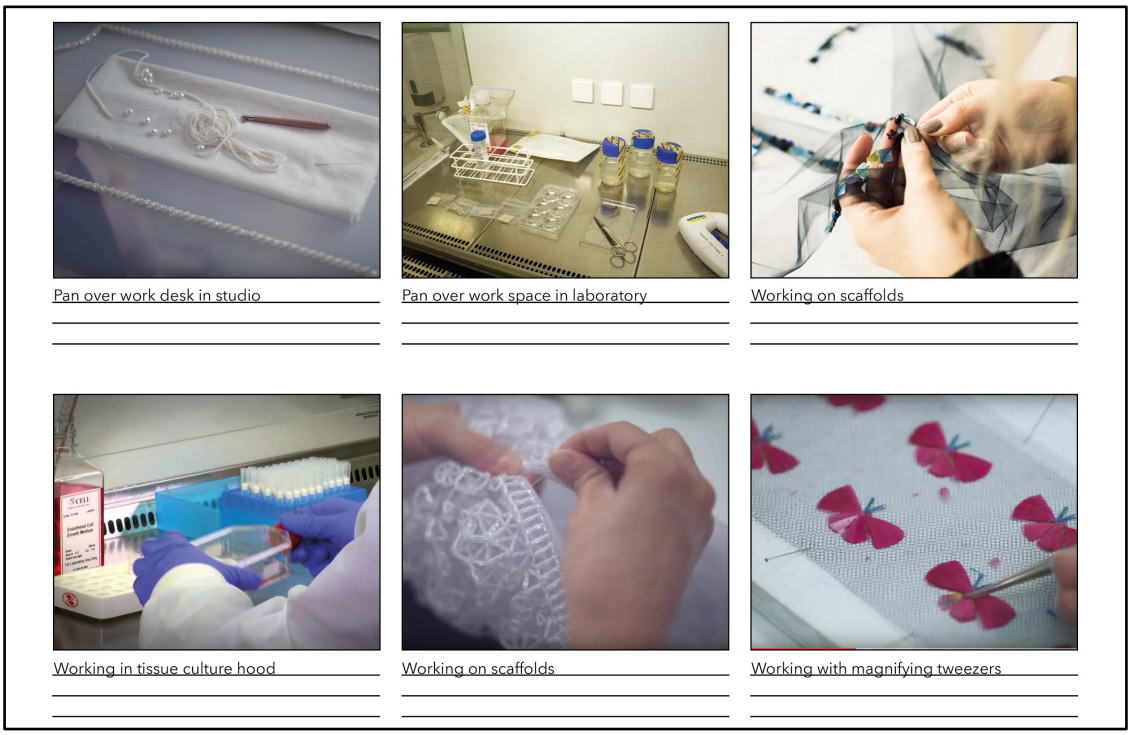


Figure 6.22

Section of storyboard developed for the 'Behind the Scenes' film

Carefully storyboarded, the film cut between the design studio and the tissue-engineering laboratory. The same worker (myself) can be seen in both spaces working on various scaffolds and conducting different scientific procedures. The concept of haute couture, and in particular the atelier, is one that has been present throughout this PhD. The connecting thread has been the importance of the hand and the impact of applying craft skill to new technologies. The film aimed to show the correlation between the atelier and the laboratory - exposing processes not often seen by people who have never entered such spaces. The principal element that linked both parts of the film is the reliance on dexterous hands and highly specialised procedures. Whether that be the hand construction of a scaffold sewn on a cell strainer, or the trypsinization of cells in a culture flask. Every element of the film was based on the techniques and processes I used routinely in the research. The final section of the film was carefully choreographed, and a choice was made not to show an end product. By not showing an end 'outcome' there was always the danger that it would feel somewhat anticlimactic. However, it was important that this film was not speculative and that it not be in any way misleading. This decision was also based on the fact that a film has the potential to be more convincing than a mocked-up prototype and can further blur the distinction between reality and speculation. Ultimately by not including an 'end product' the hope was that the focus would remain on the process of making in this instance rather than the end result.

Figure 6.23

'Behind the Scenes' film still

Figure 6.24

'Behind the Scenes' film still

The following outcomes deal with the communication of how the experiments were conducted and the subsequent results. The aim in each case was to be as accessible to as broad an audience as possible, but in particular, other designers. The development of this research led naturally to the decision to create a materials and technique archive specifically for designers

wanting to work with tissue-engineering. No such resource exists to my knowledge. Latour and Woolgar talk of ‘material dictionaries’ (1986, p. 48) and how these are subsumed in the pursuit of results. In contrast, this research looks to expose, develop and use these materials; to highlight their potential in developing new products and ways of working, ultimately providing new knowledge to the field of textiles and more broadly tissue-engineering. It is important to note here that this research is not about uncovering a new ‘scientific discovery', but about developing a new textile discipline within the laboratory. Through the course of the research, the development of design specific methodologies within the laboratory space has been necessary. The intention is that, through the archive, these skills will be transferable to others who have base-level tissue culture skills.

The format for the archive documentation went through several evolutions during the research, from the Constructed Experiments (see Appendix 2) through to the documentation of the final material archive. The final layout consists of a material information page which records: a physical material sample, the thread diameter (size), the structure of the thread, and any notes such as where it was sourced. Page two documents the information of the experiment carried out; date, cell type, media type and all other materials seeded. Page three details the aim of the experiment and the protocol used. Page four has a diagram of how the material was seeded and any additional notes. Finally, any subsequent pages document the results. This format is designed so that pages two through the end can be reproduced and included as new experiments are carried out. As with any written or pictorial account of a manual process, it will never be sufficient to explain the techniques involved fully. However, by using a combination of images and written devices, it is hoped that the documentation of the archive and how to replicate the experiments are more comprehensive than standard experimental protocols routinely found in scientific papers. By also setting up a format and presenting all of the materials seeded in the same manner, it is a resource that can be expanded upon indefinitely by myself or others.

Cotton

MATERIAL SAMPLE

MATERIAL SIZE	170 microns (0.17mm)
MATERIAL STRUCTURE	High S Twist 60/1nm
NOTES	• Fabric source: http://www.handweavers.co.uk/cgi-bin/sh000001.pl?WD=high%20twist%20cotton&PN=white60_1HTC_120_2%2ehtml#SID=116 • Fibre was 'wetable', but did twist in on itself in liquid • Autofluorescence - does not appear to auto-fluoresce green, but does slightly in red

Experiment 1

DATE	25.01.2016
CELL TYPE	HUVECs *(Human umbilical vein endothelial cells)*
MEDIA TYPE	Endothelial Growth Media 2 (EGM2) *Made by Promocell*
MATERIALS SEEDED	Cotton, Horsehair, Milk, Mohair, Nylon Monofilament, Polyester, SeaCell, Silk, Silk/Steel, Soya

AIM	To assess cell adherence, viability and orientation on a range of 10 different yarns

PROTOCOL

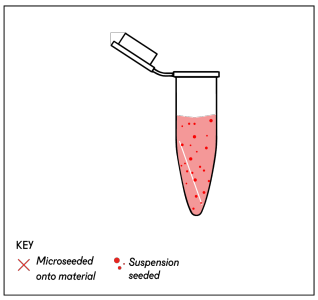
SEEDING

- Grow sufficient number of HUVEC cells to be able to seed all materials - for this experiment each material needs 50,000 cells
- Using sterile tweezers transfer autoclaved material samples into separate eppendorf tubes
- Trypsinize cells, count (re-suspended in 5ml media) and make up concentration of 50,000 cells per 100ml (times by the amount needed - in this case 1ml)
- Tag half of the cells (500ml) with Invitrogen C7025 cell tracker and the other half with Invitrogen C34552 cell tracker and then mix so each scaffold has both colour tracked cells
- Pipette 100ml of cell/ media mix into eppendorf with material sample and then add 400ml of media to make up to 500ml in total
- Place closed tubes in shaker at 37 °C, at 600rpm, and leave for 2 hours
- After 2 hours remove materials from eppendorf tubes and place in separate wells of a 24 well plate. Add media from tube to cover sample. Incubate for 24hrs and then fix for imaging

FIXING

- Remove media and add 1ml of PFA to each well, leave for 30 mins
- Remove PFA, add 1ml of PBS to each well, and agitate for 10mins, repeat.
- Place each material sample on a glass slide, add 150ml of moviol and add cover slip, leave to set for 24hrs

SEEDING



NOTES

- The different material samples were autoclaved in bags in longer than the required length, they therefore needed cutting down in sterile conditions. This was done by using a sterile petri dish and scalpel blade - cutting approx. 1cm samples of each material and then transferring these to the eppendorf tubes.
- For ease in future experiments it would be better to cut down the material samples to the correct length and autoclave them in a glass petri dish so they are easily found and picked up by tweezers - small samples tend to be lost in autoclave bags and difficult to retrieve

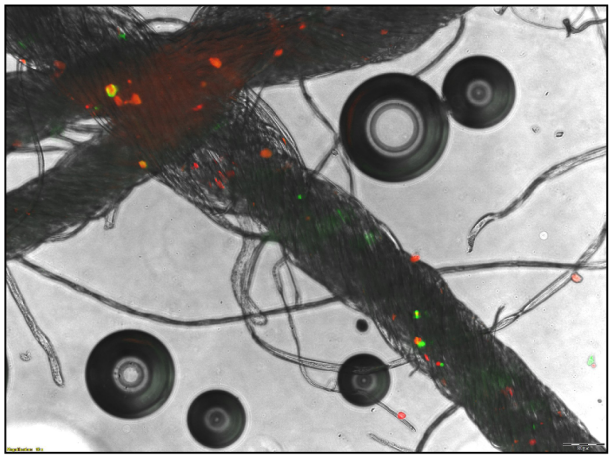
Figure 6.25 (top left), figure 6.26 (top right), figure 6.27 (bottom left), and figure 6.28 (bottom right)

Pages taken from Material Archive (see Appendix 3)

Results

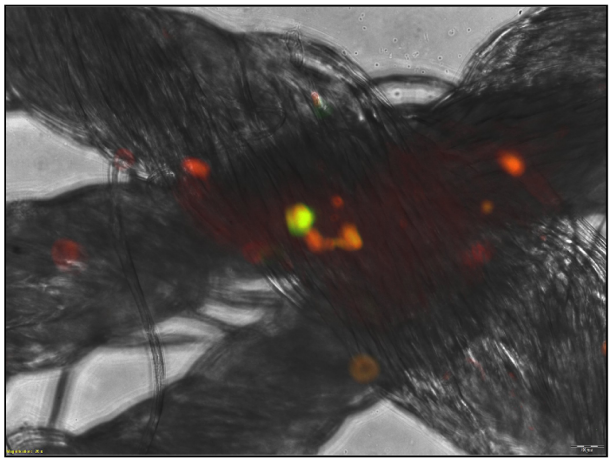
x10 magnification

Brightfield image combined with red & green cell images - composite image 24hrs post seeding



x20 magnification

Brightfield image combined with red & green cell images - composite image 24hrs post seeding



NOTES

- The Cotton was somewhat biologically compatible, there were some cells adhered but they did not look particularly healthy
- During imaging there was crossover in fluorescence between the red and green markers.

Figure 6.29

Page taken from Material Archive (see Appendix 3)

In addition to the material archive, the final scaffolds made during the research (see Chapter 5 for more) were also recorded in a similar manner (see Appendix 4). However, as well as recording the results of how successful each scaffold was when seeded, it felt necessary to find a more accessible way of communicating the most exciting outcomes. The medium of technical illustration was chosen due to its history both in science and textiles. In order to achieve the

desired technical aesthetic, I commissioned illustrator Bradley Jay to produce the drawings under my direction. The aim was to take the microscopic images produced in the laboratory and to translate them into illustrations that were both visually arresting and instructive. Creative direction was provided to help achieve a set of drawings that visually resonated with both technical-scientific and textile illustrations (see figure 6.30 for visual direction moodboard).

There were three different scaffold structures chosen; 3 strand SeaCell™ braid, three-strand braid (one yarn nylon monofilament and other two SeaCell™) and a SeaCell™ french knot. Alongside these three scaffolds, I also commissioned an illustration of one of the materials from the archive, SeaCell™, to demonstrate the discovery of cell alignment along individual fibres in a thread. Each illustration has two variations, one where the structure of the scaffold and the seeded cells are combined (see figures 6.35, 6.37 and 6.39) and one where it is broken apart into three sections (see figures 6.36, 6.38 and 6.40); the scaffold on its own, the cells on their own and the two elements combined. This segmented view is the closest to how the images taken in the lab were constructed. When imaging using the microscope firstly the scaffold is imaged under phase contrast, which is in grayscale (see figure 6.31), then the cells are imaged under the fluorescent light in which they emit (figure 6.32) and then the two images are overlaid over one another to make the completed image (see figure 6.33). The initial thinking was that the combined illustration would be the most effective. However, once they were all completed, I find myself drawn time and again using the expanded view - to both exhibit and explain the research.

As discussed throughout this thesis, the concept of haute couture has been a significant influence, in particular, how to document the new craft knowledge and skills that have emerged. It was visiting the 'Manus X Machina' exhibition at the Metropolitan Museum of Art in New York, that provided a way of thinking about how to record and disseminate the work in the lab. It gave both context and history, with the show itself centred around Diderot's 'Encyclopédie, ou dictionnaire raisonné des sciences, des arts et des métiers', a text upon which the documentation of the laboratory work is in part based. The Encyclopédie as a publication 'marked the onset of a dramatic increase in informative content.' (Adamson, 2013, p. 59). The development of exposing craft processes and skill behind them were both notable in that it put artisanal skill on a par with scientific skill. On the other hand, '[the] tacit nature of craft results in one of the curious inversions that marks its invention: it was precisely the wide publication

of technical secrets that yielded the insight that artisanal skill is fundamentally incommensurable with discourse. Like a conjurer's trick, even when seen up close, craft process doesn't reveal itself entirely, nor can it easily be repeated.' (ibid, 2013, p. 60). Communicating tacit knowledge in a pictorial or written way is, by nature, never going to be complete. With that in mind, the intention is, with the documentation of the practice's laboratory research and results, to provide a bridge between the two disciplines - whilst also hopefully being a resource that helps other researchers to develop their own practice in the field.

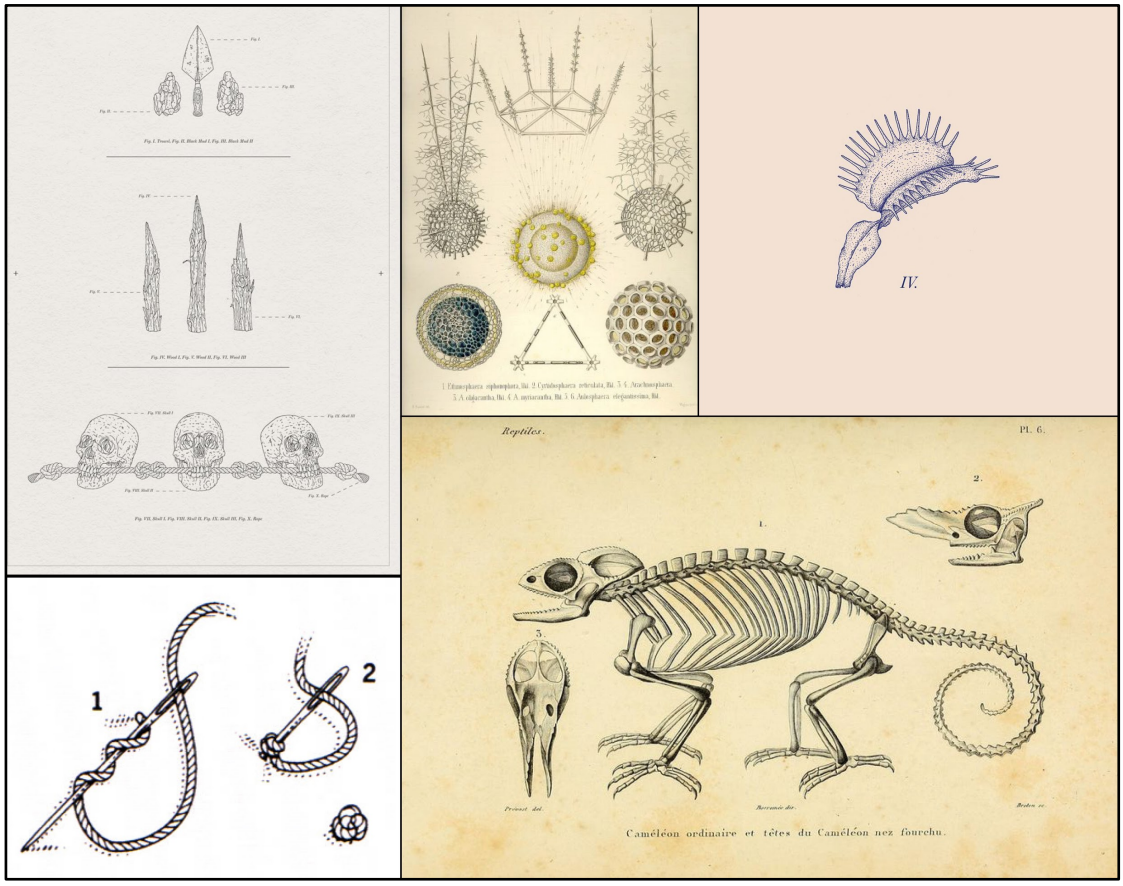


Figure 6.30

Visual direction moodboard taken from the brief for the illustrations

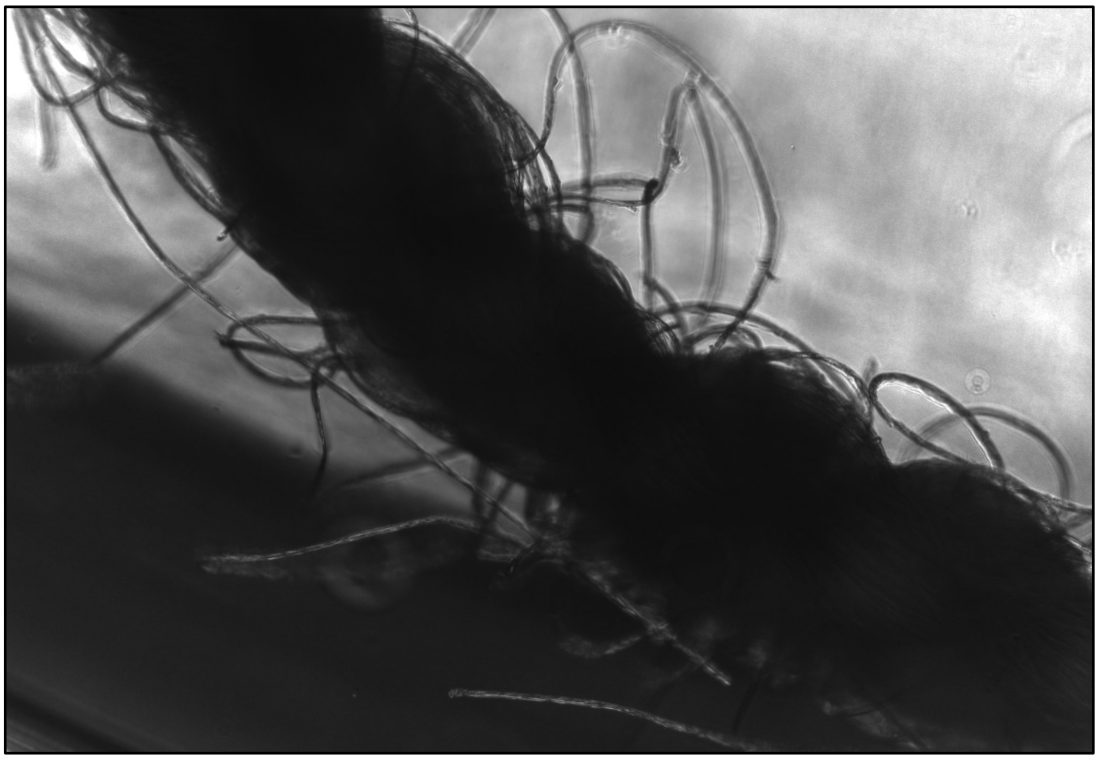


Figure 6.31

Three stranded braid, phase contrast microscopic image

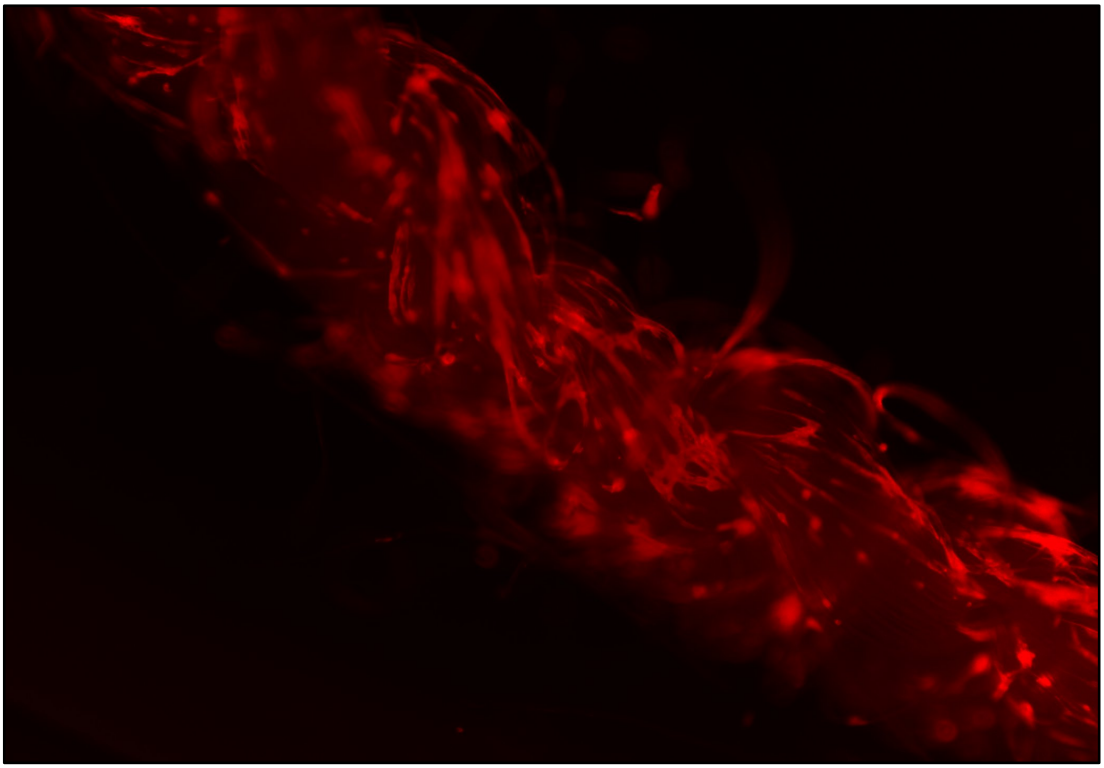


Figure 6.32

Three stranded braid, red fluorescent microscopic image

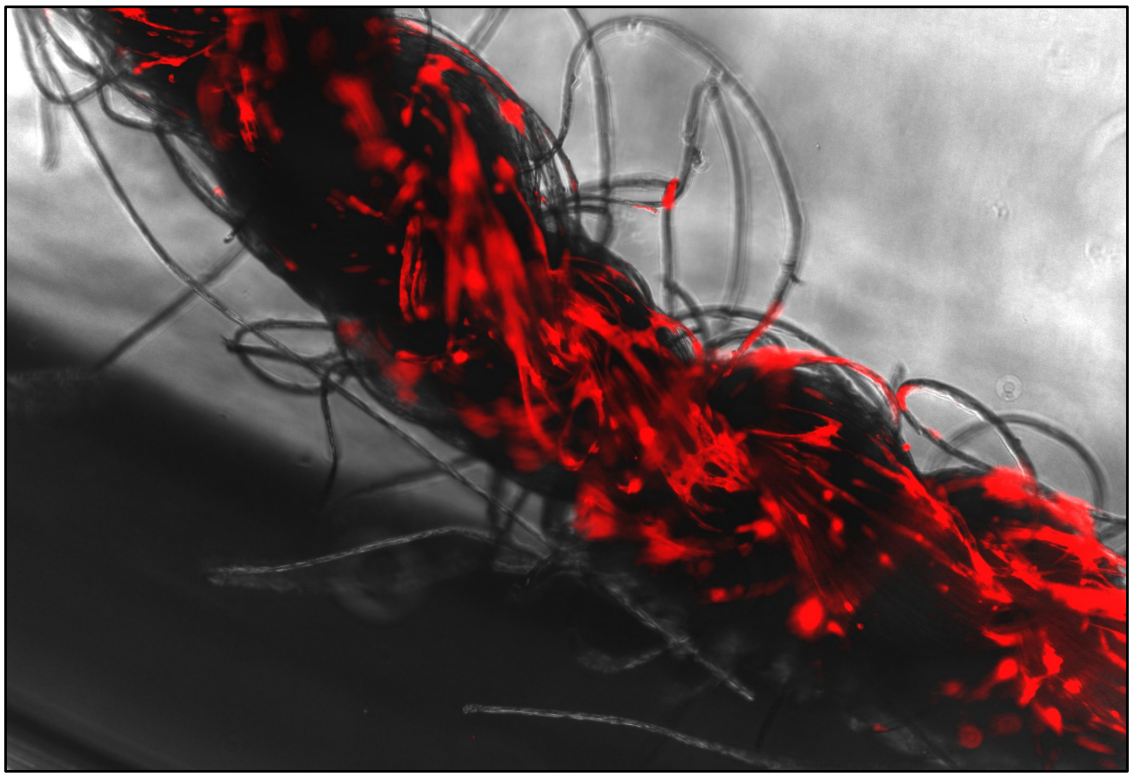


Figure 6.33

Three stranded braid, phase contrast and red fluorescent microscopic image

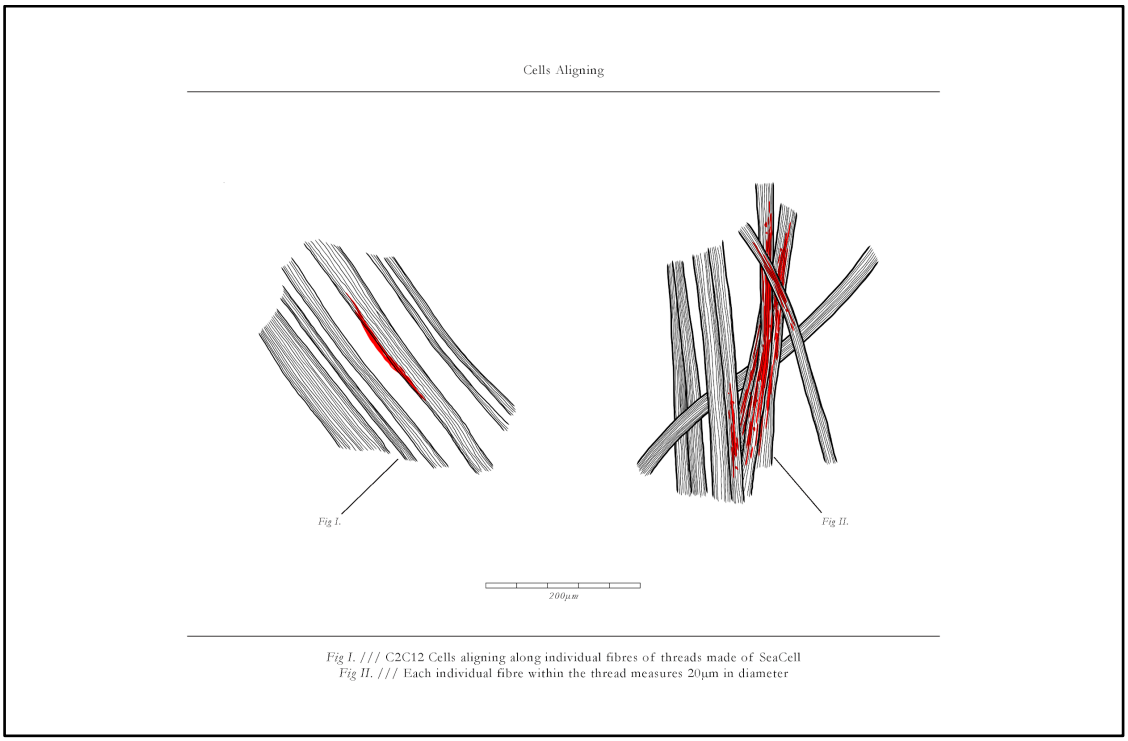


Figure 6.34

Commissioned illustration (by Bradley Jay) of C2C12 cells aligning along individual SeaCell™ fibres

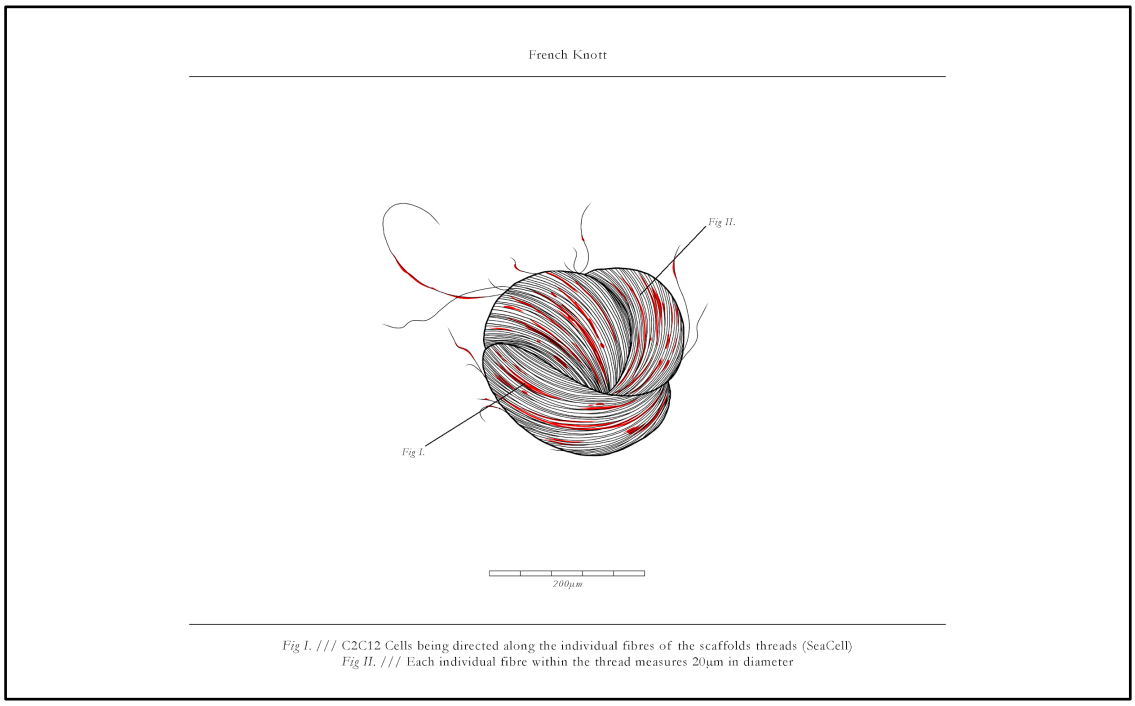


Figure 6.35

Commissioned illustration (by Bradley Jay) of C2C12 cells around a SeaCell™ French knot scaffold

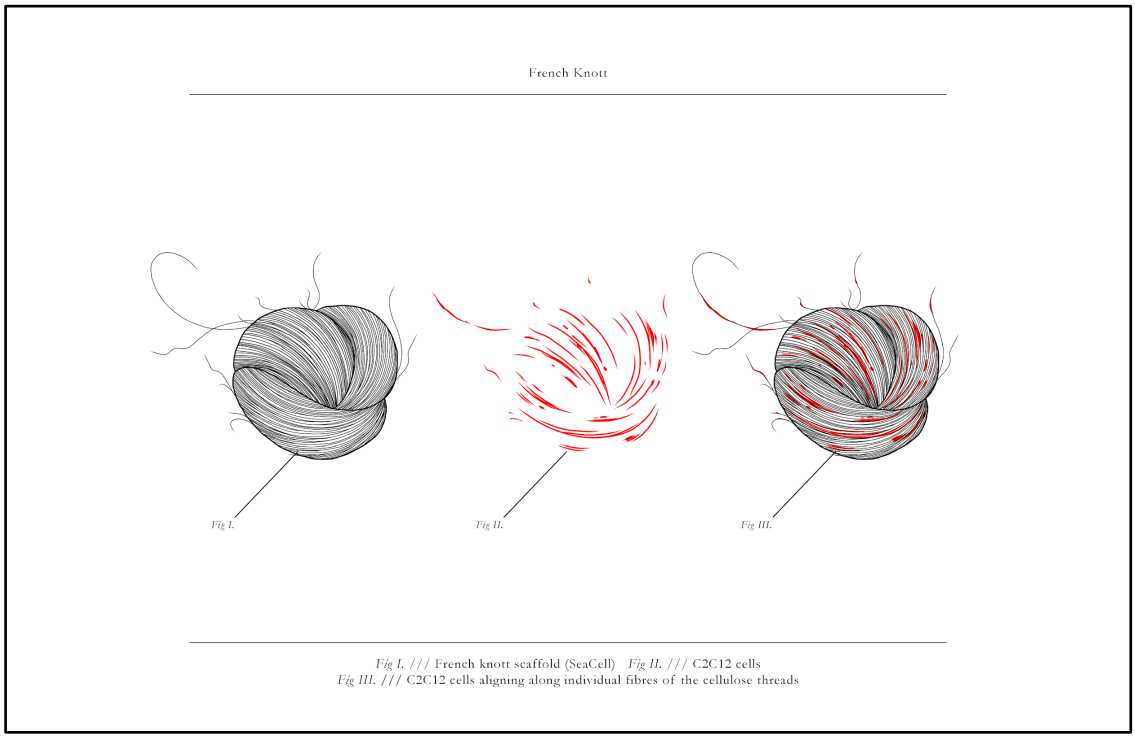


Figure 6.36

Commissioned illustration (by Bradley Jay) of C2C12 cells on SeaCell™ french knot scaffold, three part view

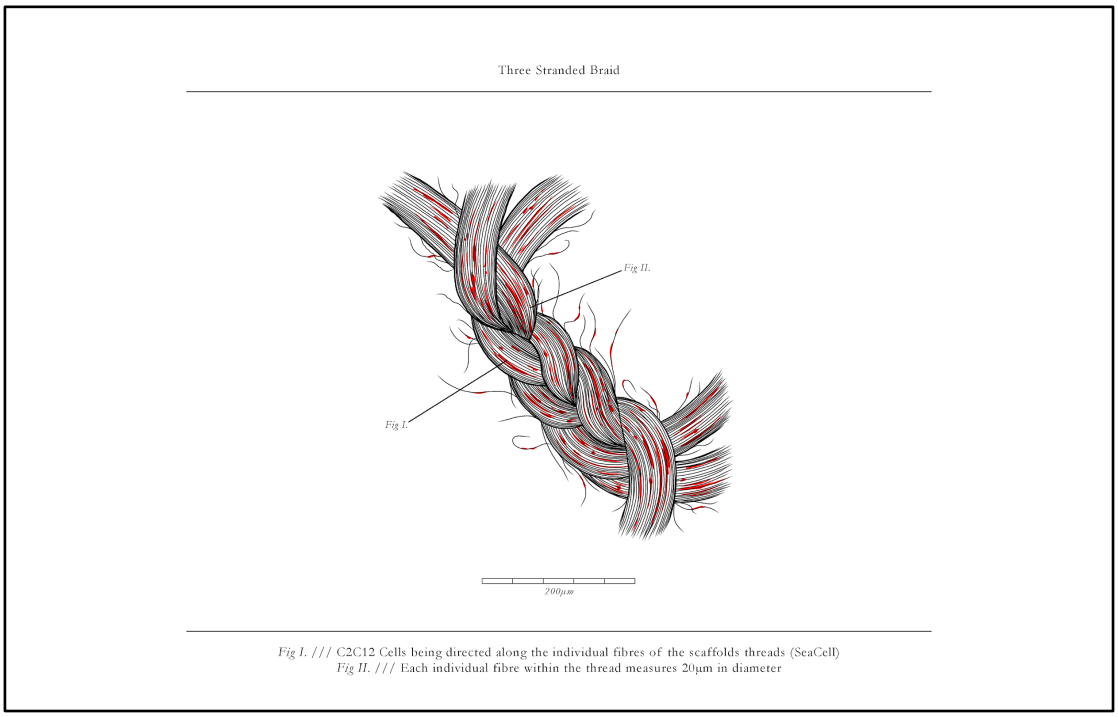


Figure 6.37

Commissioned illustration (by Bradley Jay) of C2C12 cells around a SeaCell™ three strand braid scaffold

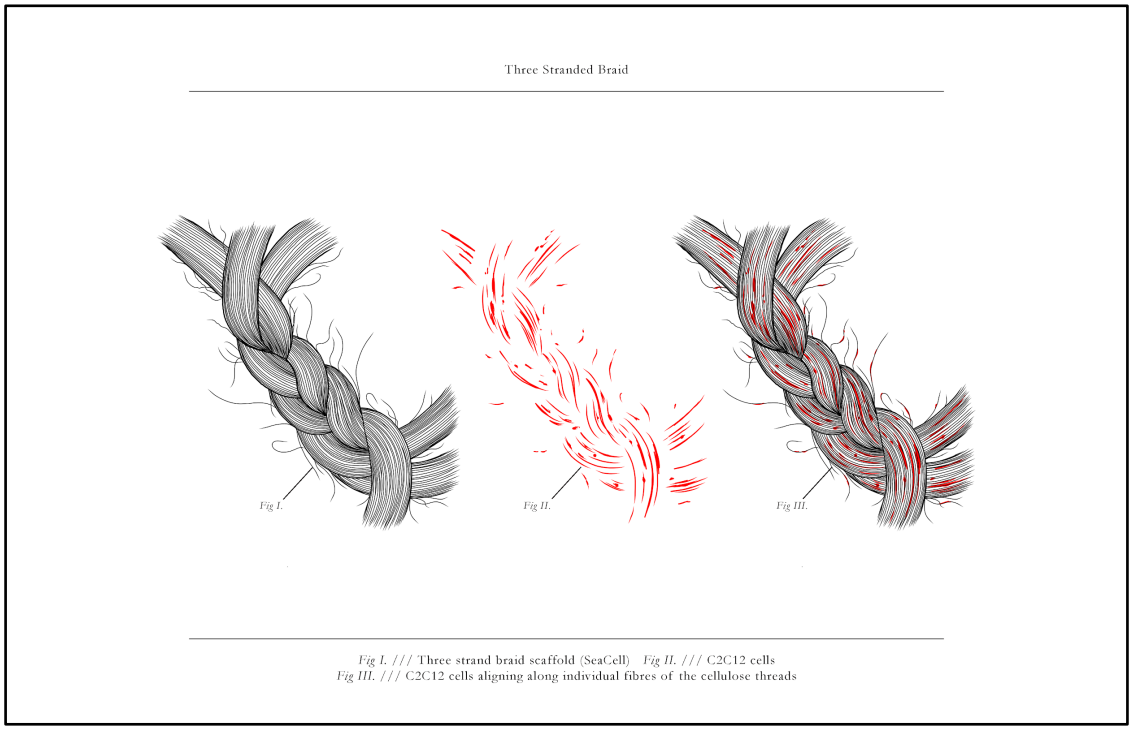


Figure 6.38

Commissioned illustration (by Bradley Jay) of C2C12 cells around a SeaCell™ three strand braid scaffold, three part view

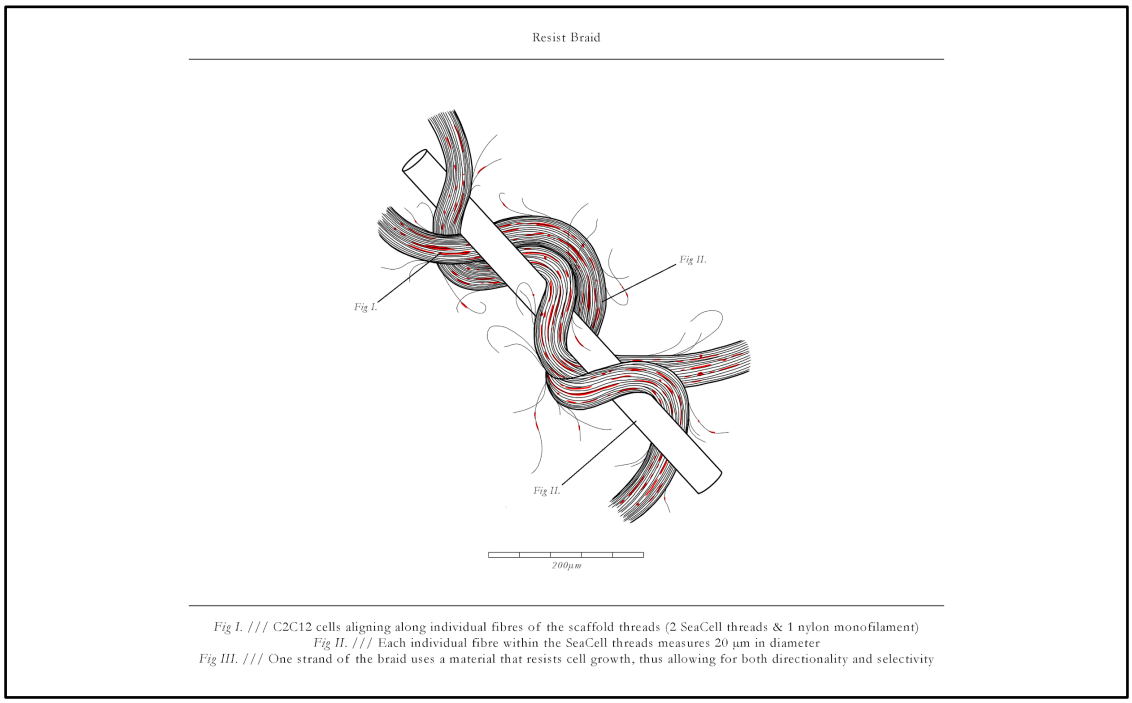


Figure 6.39

Commissioned illustration (by Bradley Jay) of C2C12 cells around a SeaCell™ and Nylon Monofilament three strand 'resist' braid scaffold

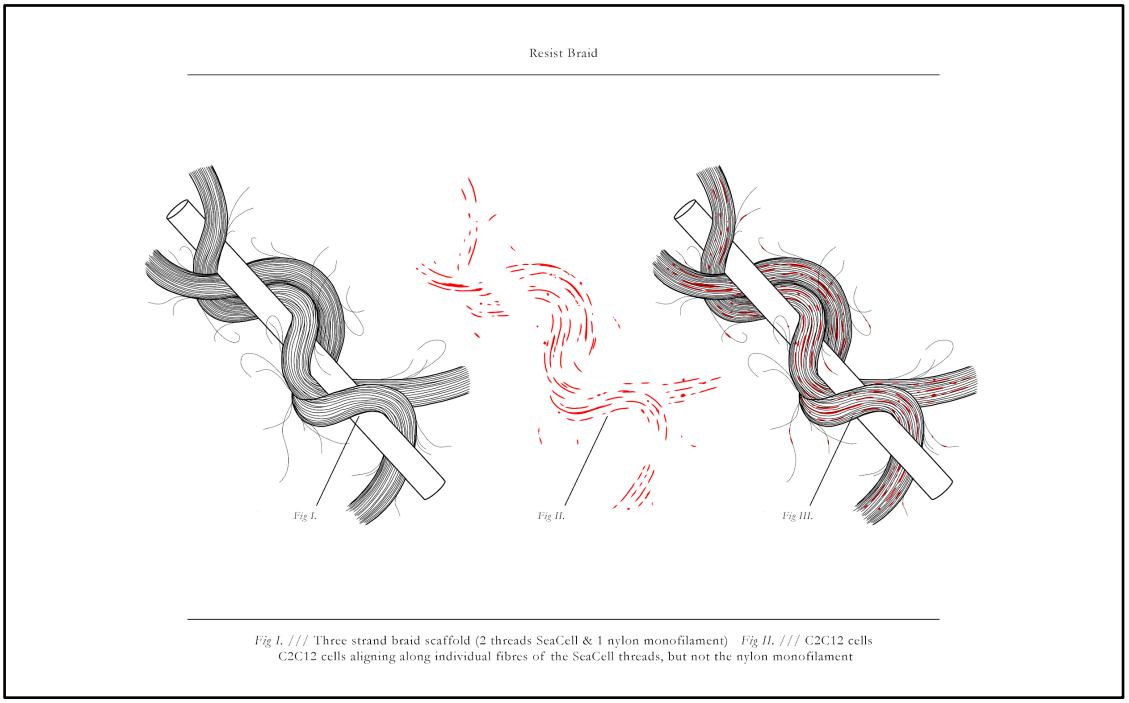


Figure 6.40

Commissioned illustration (by Bradley Jay) of C2C12 cells around a SeaCell™ and Nylon Monofilament three strand 'resist' braid scaffold, three part view

6.5 Tissue-Engineered Textiles: a Craft System

> Over the last thirty years, a new systemic understanding of life has emerged at the forefront of science. It integrates four dimensions of life: the biological, the cognitive, the social, and the ecological dimension. At the core of this new understanding we find a fundamental change of metaphors: from seeing the world as a machine to understanding it as a network.
>
> (Capra, 2015, p. 242)

The final section of this chapter was originally intended to be quite different. While being a designer immersed in a lab, it is easy to become desensitised to language around biology, language that can be, in the majority, borrowed from engineering terminology. The issues around framing living materials in this way were covered in the very beginning of this thesis (Chapter 2), and it felt pertinent to revisit it at its close. It was intended that this part of the writing would cover the final laboratory work and discuss it in the context of a platform technology. Instead, what it presents is first and foremost a 'craft system' where the processes and outcomes are interdependent with one another. It also takes a macro view – encompassing the totality of the research as a system - where each part is connected, as well as to the broader design community and culture at large.

When framing the final material archive and scaffolds as a platform technology the analogy was to draw attention to the fact that by approaching the experiments from the bottom-up the control of cell growth and orientation could be used to produce structures for any number of applications. Rather than set out to make one type of tissue, with more research, the results from this body of work could contribute to knowledge that could be implemented into a range of applications — hence referring to it as a platform technology. However, it was in returning to an influential text, studied early in the PhD, that gave a new perspective to the work. The text in question is 'The Systems View of Life: A Unifying Vision' by Fritjof Capra and Pier Luigi Luisi. The quote at the beginning of this section is taken from a review of the critical points of the book, written by Capra. The ideas resonate with a craft approach – one where all elements in the making of a piece are interconnected and never quite the same twice. This fact is never more valid than when working with living materials, giving the analogy of interchangeable, and controllable parts serves only to give us a sense of control and complete reproducibility in theory.

The notion of interchangeability suggests discrete parts that can be swapped out with relative ease. This theory is far from the case and, as the opening quote attests, this is an idea which is beginning to give way. At the end of the practical work, an interview was conducted between two of the PhD's supervisors, Professor Carole Collet and Professor Lucy Di Silvio, and myself. The intention was to unpack some of the ideas and results that had come about during the research. It was conducted to form a chapter in an upcoming book published by Bloomsbury entitled 'Crafting Anatomies' (to read the entire interview, see Appendix 6). Below is an excerpt from the interview that discusses the importance of interconnectivity and interfaces - in relation to tissue-engineering and this research.

Carole: The products you're creating, I call them silent interfaces. Because they're silent in the body, they're not active, but they are supporting the activity of the cells growing in alignment.

Lucy: Well in scientific terms we talk about tissue interfaces. Tissues exist as multiple types and are assembled in a complex organ system. Tissues interface with a seamless integration, with the tissue-to-tissue interfaces exhibiting a gradient of structures and properties that serve a number of functions. Successful tissue-engineering requires a direct structural interface with the host tissue.

Carole: Ah so that's interesting.

Amy: I think that's one of the things I remember from very early on, going back to how this all began, is when I came into your office and you talked about how nothing in the body grows in isolation - everything is interfacing or integrating with something else. And when you work in a lab there's sometimes that danger that you end up working with one cell type on its own, and it's never that way in the body.

Lucy: I think that's a really important point that you bring up. Because even scientists; everyone is specialized in their area "I'm a soft tissue biologist," "I'm a hard tissue biologist." etc. But no tissues exist in isolation. So, when you are developing your tissue-engineered bone for example, you've got to think of what tissue that's going to interface with, and it's going to interface with soft tissue.

Amy: I think that links back in some way to things about textiles and creating. When you're working with materials, many times you're trying make something or a product where you're not just working with one type of material. You're trying to construct something with materials of different characteristics and working with how those materials want to behave.

Carole: So effectively you've designed an ecosystem - a textile-based ecosystem that will support the living cellular system. Because the ecosystem is not just a fiber, it's the structure also.

(Congdon, Di Silvio and Collet, 2018)

Regarding the work in the laboratory, the concept of a system, where all elements are interdependent on one another, is a far more useful one than any alternative engineering metaphor. From the scale of the fibres that make up the thread, to the way those materials are combined through to how they are seeded and beyond, there is a dynamic ecosystem at work, and when one part is changed, it has an inevitable effect on the whole. A system's way of thinking is also valuable to view the work of this PhD in its totality. When speaking of different systems, Capra discusses the different realms in which they operate; 'Biological networks operate in the realm of matter; social networks operate in the realm of meaning.' (Capra, 2015, p. 248). The experiments in the lab operate in the realm of matter, whereas the contextualisation of their possibilities operates, when successful, through informed speculations in the realm of meaning. 'As communications continue in a social network, they form multiple feedback loops which, eventually, produce a shared system of beliefs, explanations, and values — a common context of meaning, also known as culture, which is continually sustained by further communications.' (ibid). The concept of loops links to Daniel Fallman's research model, looping or iterative feedback is how all of the projects within the umbrella of this PhD are interconnected. The speculative prototypes enabled conversations which allowed the laboratory work to happen; the laboratory work informed new speculations, new ways of working called for new tools and results called for new ways of representing them.

It can, of course, be argued that I am merely playing semantics, but I would argue this makes it no less important - how something is presented influences how others respond to it. Ultimately, we should be thinking in terms of systems, be that locally in the materials we use through to the products we make and the impact of their lifecycles on culture and the planet. As designers, we do not create in a vacuum - what we make, how we make it, and how that is presented all have implications, implications we are in some way responsible for. Increasingly it is not enough for consumer brands to only lightly engage with sustainability, LCAs (life cycle analysis) are ever more important – to understand where and how what we make has an impact on our planet. It is imperative that we do not naturally assume that new technologies, such as biofabrication, because it harnesses nature, is better than what preceded it. This very point was echoed by NASA scientist Scott Bolton, Principal Investigator of NASA's Juno mission to Jupiter, at the Biofabricate 2017 summit. He argued that just because a technology is new does not make it better for the planet – we must not look back in another 20 years' time and find we have invented the next plastic. (Bolton, 2017)

One last thing which is essential to note is that one of the main reasons haute couture is consistently referenced is that, due to the complexity, skill and timescales involved in tissue-engineering, it would only lend itself to the highest end products. This issue is not as much a constraint in regenerative medicine where the economics work. Having said all of this the fundamental importance of this PhD is not the specifics of the type of technology used, but more the merits of the approach - what value is brought by a craft/ maker's perspective. By being comfortable with the messy, and the more poorly defined edges of things, they can contribute to a systems' view of the technology - helping both to develop the products and to open up the broader debate into what we want our collective product and ecological future to be.

6.6 Conclusion

The beginning of this chapter presented a range of new tools designed directly in response to working the laboratory. Through the lens of rethinking how to make different items, and how to solve pivotal issues that had arisen, the culture dishes embody a craft led approach to using the technology of tissue-engineering. They help to make manifest abstract ideas in line with Bachelard's Reified Theory. Making palpable some of the ways our future products may change, in particular, their manufacturing processes. The first two dishes present a way of growing an artificial flower made historically in the parurier floral métiers, the wells shaped as

petals to only grow what is needed and no more. The second dish attempted to solve the problem of scaffolds floating in vitro. This solution was achieved by hybridising a traditional textile embroidery hoop with a cell strainer and culture dish insert. Even though the culture dishes could not ultimately be used in the laboratory, they still embody the thinking that craft and craft processes can bring to the tools of the laboratory. As pieces, they can also be viewed as 'Super Objects' in the context that they contain layers of meaning (Mazanti, 2011). Not only practically how they could be implemented but also linking to the full implications brought about by growing our future products.

The majority of the rest of the chapter covered the thinking around how to communicate the research. From the 'informed speculations' that grew out of the necessity of wanting to present snapshots of the research at various exhibitions, there developed a new way of thinking about speculative design, and how and when, it can be a useful tool. By situating all of these prototypes alongside experiments from the laboratory, and presenting only that which is genuinely informed by a working understanding of the technology, it helps to ground them in reality. The chapter then moved on to discuss the communication of the research, which took place in the laboratory itself — detailing first the development of a Materials Archive, which is designed to be an evolving and dynamic resource, both for this research and the broader design community. Through to the commissioning of illustrations showcasing the final scaffolds; and finally to the creation of a new 'behind-the-scenes' film, which juxtaposed, and drew comparisons, between the textile atelier and the tissue-engineering laboratory. All of these elements were designed to open up the processes and results of the research and to make them more accessible to a broader audience. This will always remain an imperfect task, as it is impossible to truly capture tacit knowledge in either written, pictorial or even video form. Taken together, they give a way into the research to encourage others to follow suit and 'get their hands dirty'.

The final section of this chapter ended with thoughts on the importance of systems thinking and how this relates to the research both locally within the laboratory, but also holistically as a body of work. It has been an extensive journey to come back to thinking of the work in this way, and it feels both fitting and vital to do so. By viewing living materials, and the potential products we may make as part of a larger whole, the aim is to make more ecologically sound decisions as designers. In a more specific way, by framing the practice in the laboratory, it has a strong relationship to a craft approach to making - one which is always aware of the implications and interdependency of actions and processes.

CHAPTER 7:
Concluding the Research: Findings and Future Steps

7.1 Introduction

This concluding chapter is intended to cover how successfully the research addressed the research aims, objectives and the question: "Can the integration of textile craft with tissue-engineering techniques lead to the development of a new materiality for future design applications?" The chapter does this by outlining the findings of the PhD and unpacking the relevance of the results. It then moves on to present the new contributions to knowledge made by this PhD. It concludes with a discussion on the potential next steps for the research and the implications for the disciplines of textile craft and tissue-engineering.

7.2 Achieving the Aims and a Brief Summary of the Research

The aims and objectives of this PhD are detailed in the introductory chapter to the thesis, for ease, they have been included again below. This section of the chapter will discuss if, and how, these aims were met as well as summarising the research undertaken during the PhD.

Aim 1:

To produce an innovative body of work that articulates the complex implications of utilising biotechnology for textile design practice.

Aim 2:

Develop a body of work which demonstrates what is achievable through integrating a textile-based craft approach into the discipline of tissue-engineering.

Aim 3:

Create a Materials Archive as an entry point and resource for other designers wishing to work in the field. Alongside a range of scaffolds that have applications for both regenerative medicine and future products.

The research achieved all three of the aims it set out to, with varying degrees of success. The first aim was perhaps the one which was not fully realised, due in part, to the shift in research focus, which happened as the PhD progressed. The original intention was to produce a more significant body of speculative work which would attempt to fully unpack the complex implications of using living materials in textile practice. As the direction of the research changed and relocated itself firmly in the tissue-engineering laboratory, the focus became less about

articulating the implications and more about understanding what the current capabilities of the technology are. Towards the end of the PhD, the 'informed speculations' attempted to bring a more grounded approach to communicating the ways in which tissue-engineering might be used in the future. To truly achieve the first aim, further work would need to be done to research and test the most effective modes of communication - due to the fact, discussed in Chapter 3, that there are issues with how much current speculative design is disseminated and consumed.

The second and third aims of the PhD were addressed much more thoroughly. Aim two was the one most comprehensively answered of all of the three, the development in particular of the Materials Archive and subsequent scaffolds both embody the value brought by a textile perspective to tissue-engineering. Through a 'bottom-up' approach to exploring materiality, several viable materials were identified, as well as textile techniques (such as resist) that could be incorporated into tissue-engineering. The third aim was practically achieved, meaning that both an archive and a range of scaffolds were created. Whilst the archive is definitely far more comprehensive than existing descriptions of processes found in scientific papers; it would benefit from ongoing iterations to be as instructive as possible to other designers wishing to enter the field. Finally, the scaffolds produced during the research have potential applications in both regenerative medicine and future consumer products. However, more work is needed to develop them to the point of readiness for either area.

7.3 Original Contribution to Knowledge

This next section of the chapter outlines the PhD's original contribution to knowledge. The contributions, evidenced throughout the thesis, are synthesised here and presented as simply and concisely as possible.

This PhD has made contributions to knowledge in the field of textiles and tissue-engineering in the following ways:

- **A New Textile-Based Material Archive for tissue-engineering**

  The first contribution to knowledge is the creation of a novel textile-based material archive for tissue-engineering (detailed in chapter 5). Part of the impetus for the creation of the archive was that no such resource could be identified while researching this PhD.

- The archive is unique because it includes multiple experiments with ten different fibre types from across the textile classification spectrum. Some of which, such as mohair and SeaCell™, have not been found to be used in tissue-engineering before. In the scientific literature, there is a precedent of SeaCell™ being used for the treatment of wounds and as a textile that prevents bacterial growth (Hipler, Elsner and Fluhr, 2006; Zikeli, 2006; Fluhr et al., 2010). Although, in all literature searches conducted to date on SeaCell™, there are no papers where it has been used in tissue-engineering. This lack of literature suggests it is a new material, that shows promising biocompatibility, that has not yet been researched for applications in regenerative medicine.

- The second factor that makes the archive singular is that there is no existing equivalent resource. Ten materials, comparable in size, were all seeded in the same way using the same cells and protocols. The protocols developed are repeatable, which allows the resource to be indefinitely expanded in the future.

- Finally, during the research for the archive, the experiments specifically demonstrated cells aligning along the individual fibres, that make up the threads themselves. This alignment was primarily observed in the case of the SeaCell™ seeded with C2C12 cells. The impact of scaffold scale and cell orientation has been documented previously but not in this combination of material and cell type.

- **New Textile Scaffold Structures for Cell Attachment**

  The second contribution to knowledge is through the development of a number of handcrafted textile scaffolds that show cell attachment, controlled orientation and in some cases, bioselectivity (detailed in chapter 5).

  - Through the demonstration of understanding the impact of scale on orientation, which is confirmed by the literature, this knowledge was combined with textile construction techniques to create a number of scaffolds which show directional cell alignment. Whilst the impact of scale is presented in the literature, no papers were found detailing this information being used to

construct textile scaffolds that control cell orientation. By demonstrating the morphology of the C2C12 cells elongating along the individual fibre, this knowledge was translated into larger structures, e.g. following the line of the braid yarns.

- Secondly, in relation to the scaffolds created, also evidenced was the use of the textile concept, and technique, of resist. This was done by translating the results of the material archive seeding, where some materials supported cell growth (SeaCell^{TM}) and some that did not (nylon monofilament), and using it in textile scaffolds. This understanding was combined with textile construction techniques, in particular, a three-stranded braid, produced scaffolds that demonstrated bio-selectivity where the cells only attached to specific sections of the structure.

- **A New Tissue-Engineered Textile Methodology**

  The final contribution to knowledge made by this PhD is in the development of a 'bottom-up' textile craft informed methodology - working with materials, understanding their capabilities, and letting this inform the way scaffolds are constructed.

  - The methodology developed enabled the creation of the first two contributions to knowledge. It is a 'bottom-up' methodology specifically devised for the creation of textile scaffolds for tissue-engineering. This method is a marked difference to how scaffolds are typically designed - where the desired tissue type or organ is identified, a suitable material is selected, and a scaffold created. The methodology developed in this thesis foregrounds the value of a textile maker's knowledge – using the understanding of structure-property relationship, combined with knowing how a cell grows on an individual fibre and how that will translate from fibre-to-yarn-to-structure-to-finished object. As a methodology, it was developed by synthesising a textile craft and a tissue-engineering approach to material exploration.

    By combining the rigours of 'design of experiment' so that each variable can be easily defined and assessed, alongside an open-ended craft exploration of material and form, a new model was developed. Although the terms 'top-

down' and 'bottom-up' have precedence in engineering, science and technology, and biomimicry; to date there has been no synthesis and development of the ideas concerning textiles and tissue-engineering. It therefore constitutes a new contribution to textile and design-science practice. There is the potential for this approach to be used to make any number of scaffolds. What was developed was a system, rather than a platform, which is interdependent, iterative and connected. I would also finally put forward that this particular contribution to knowledge should not just be limited to tissue-engineering. The essence of the methodology and approach could be adapted to any scientific field to which it is applied.

7.4 Future Work

In addition to discussing what has been researched and uncovered as part of this practice-led PhD, I felt it necessary to dedicate a section of this concluding chapter to the potential next steps for the work. To present some of the most exciting possibilities that, due to lack of either time or scope of the work meant I was not able to pursue during this body of research. Each bullet point below is intended as a trigger or stimulus point and is by no means exhaustive as a list. Overall the most exciting future work would be as multifaceted as possible with all manner of areas of research emerging through the integration of design and science practices.

1. *Expansion of the Material Archive*

   The archive developed during this research is, in many ways, a starting point. Designed to be comprehensive, the archive selected a range of materials from across the textile classification spectrum. All of the materials were seeded using the same protocol and a variety of cell types. Through a process of experimentation, and screening, with different materials, two were selected as the most successful: Milk and SeaCell™. A number of replicate experiments were undertaken to prove the validity of the results (see Chapter 5 and Appendix 3). Through this, it became clear that many different factors affect the success of seeding any given material. Therefore, the archive is something that could be continually ongoing with infinite possibilities as to the materials, processes and cells used. It could systematically examine multiple variables to see what effect they have on the outcome. For example, one could do an entire body of experiments just investigating cotton; from different yarn twists, to dyed vs undyed etc. This type of process and knowledge accumulation is that of a craftsperson

dedicated to understanding the material with which they work and how to manipulate it with the utmost finesse.

Another aspect of the archive which could be fruitful for further development is the format in which it is presented. Conceived to be more comprehensive than the existing scientific papers and literature, it understandably still falls short of capturing, and communicating, all of the nuanced tacit knowledge embedded within laboratory processes and techniques. This knowledge is something that will never be adequately captured, but further developments could attempt to get it closer to being realised - for example, through the integration of video and audio components, or further descriptive photography and illustrations. Ultimately, nothing, in my opinion, can replace hands-on working experience with a technique or material, but an archive such as this can be a helpful starting point to get an idea of a process before working with it, or once some skills have been learnt, its contents could be used to develop new avenues of research.

2. *Hand Crafted Scaffold Development*

As documented in Chapter 5, the recording of some of the results, especially with regards to microscopic imagery, were incomplete; unavoidable at the time due to issues with equipment. As discussed, it was not the aim of this PhD to reveal or 'prove' a new scientific discovery; rather it was to highlight the value brought by applying a textile craft approach to working with tissue-engineering. This would likely lead to a more significant discussion on the nature of proof and how that can be exhibited in different disciplines. One of the next steps in the work, to prove it scientifically, would involve the creation of duplicate samples and the replication of experiments to validate the results. This repetition of experiments is something that, due to timeframes, it was not possible to complete within the PhD. It is, therefore, a logical next step in the journey of the research.

Alongside replicating experiments to prove the ability to direct cell growth, both directionally and selectively on different scaffolds, it is also necessary to recognise that handcrafting individual scaffolds for regenerative medicine applications is neither practical nor cost-effective. However, this type of approach can provide a rapid way to

iterate and develop new scaffold designs quickly. As we move towards personalised or custom-made scaffolds, this could provide valuable insight. This would mean once a successful scaffold has been created for a specific application its production can then be scaled-up appropriately if needed.

3. *Publish & Involve others in the development of the work*

   Following on from the above next step, which discusses creating replicate scaffolds and validating the research results, is an outcome which Professor Di Silvio and I have discussed - which would be to formulate the findings into a paper for publication. This paper would allow the dissemination of the research to the broader scientific and design communities. Demonstrating new outcomes in the field of tissue-engineering using a novel approach would be a direct outcome of the PhD work. It would also open up the discussion further as to the value of interdisciplinary collaboration, and what can be achieved through bringing a range of different expertise and approaches into the laboratory.

   In addition to a paper, as discussed in chapter 5, there is a potential to write a project proposal or brief for the major project of the next cohort of BSc students completing a rotation in the Tissue Engineering & Biophotonics Laboratory at Kings College London. This would ask them to further validate and explore SeaCell™ as a material for use in tissue-engineering. It would be fascinating to see how they approach using the material in comparison to the way I used it in my own practice. Opening up the work, and the approach, to further collaboration with others would be an incredibly valuable next step for the research and its potential impact on both the fields of textiles and tissue-engineering.

7.5 Concluding Thoughts

This PhD has been an almost seven-year journey exploring what it means to be a textile craft practitioner working with scientists, in particular, in tissue-engineering. It has taken me from critically engaging with the potential of the technology and using design as a thought process to help unpack some of the future possibilities and implications for design, through to the integration of textile craft techniques in the production of scaffolds within the tissue-

engineering laboratory itself. The entirety of the research has been a process that has led me to understand what my own personal research interests are and what I see my contribution ultimately being to the field. I have shifted from using speculative work to comment upon the potential of the technology, to a place where I became increasingly invested in what is currently possible in the laboratory and wanting to be constructively involved. I have a desire to work practically to help shape the future potential of this technology by being embedded in a laboratory, by being immersed in the technology, and by understanding and engaging with the science firsthand. Throughout the PhD, it has been a rewarding, and at times, challenging experience, though always a fascinating process. It has helped lead me to a career where, daily, I get to work side by side with scientists in the lab and be involved in the design of materials from the very inception. I hope that this research is a useful springboard for any researchers who wish to follow suit. I encourage the next wave of designers to understand that in order to engage with science it is immeasurably valuable to have a working understanding of it so that you can personally define what your own unique skill set brings to the table.

49,318 words

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APPENDIX 1

GLOSSARY

GLOSSARY

Anterior Cruciate Ligament

"The ACL is a tough band of tissue joining the thigh bone to the shin bone at the knee joint. It runs diagonally through the inside of the knee and gives the knee joint stability. It also helps to control the back-and-forth movement of the lower leg."

(nhs.uk., 2018a)

Atelier

"Atelier is a workshop or studio, especially one used by an artist or haute couture fashion designer. In art, the atelier consists of a master artist, usually a professional painter, sculptor, or from the mid-19th century a fine art photographer, working with a small number of students to train them in visual or fine arts. This very word has also taken on other similar meanings, indicating a place of work and study of the haute couture *fashion designer*, hair stylist and artists in general."

(Apparelsearch.com, 2018a)

Biocompatibility

"Biocompatibility is a general term describing the property of a material being compatible with living tissue. Biocompatible materials do not produce a toxic or immunological response when exposed to the body or bodily fluids."

(Spine-health, 2019)

Biofabrication

"Biofabrication, originally a biomedical definition, today imagines a world of materials manufacture where future consumer products are designed and grown harnessing biological organisms. This is a new design paradigm centred on cultivating materials with living cells. Organisms such as yeast, bacteria, fungi, algae and mammalian cells are fermented, cultured and engineered to synthesize natures materials but with new functional and aesthetic properties. They share one key element: life."

(Lee, 2015)

Biopsied/take a biopsy

"A **biopsy** is a medical procedure that involves taking a small sample of body tissue so it can be examined under a microscope."

(nhs.uk., 2018b)

Biotechnology

"At its simplest, biotechnology is technology based on biology - biotechnology harnesses cellular and biomolecular processes to develop technologies and products that help improve our lives and the health of our planet."

(BIO, 2018)

Cell Alignment

Cell alignment is the positioning of cells in relation to one another and the substrate on which they are growing.

Cell Lines

"A cell line is a permanently established cell culture that will proliferate indefinitely given appropriate fresh medium and space. Lines differ from cell strains in that they become immortalized."

(Sciencedirect.com, 2018b)

Craft

Craft is defined by the Cambridge Dictionary as "skill and experience, especially in relation to making objects; a job or activity that needs skill and experience, or something produced using skill and experience."

(Dictionary.cambridge.org, 2019)

Critical Design

"Critical Design uses speculative design proposals to challenge narrow assumptions, preconceptions and givens about the role products play in everyday life. It is more of an attitude than anything else, a position rather than a method. There are many people doing this who have never heard of the term critical design and who have their own way of describing what they do. Naming it Critical Design is simply a useful way of making this activity more visible and subject to discussion and debate.

Its opposite is affirmative design: design that reinforces the status quo."

(Dunne and Raby, 2007)

Culture Media

"Any liquid or solid preparation made specifically for the growth, storage, or transport of microorganisms or other types of cells. The variety of media that exist allow for the culturing of specific microorganisms and cell types, such as differential media, selective media, test media, and defined media."

(Definitions.net., 2018)

Decellularized

"Decellularization is the process of removing all the cellular components of an organ while retaining the native composition and structure of the associated Extracellular Matrix (ECM). The decellularization process aims to remove all cellular and nuclear matter minimizing any adverse effects on the composition, biological activity, and mechanical integrity of the remaining ECM for the development of a new tissue. The process usually consists of mechanical shaking, chemical surfactant treatment, and enzymatic digestion."

(Sciencedirect.com, 2018c)

DNA

"Deoxyribonucleic acid or DNA is a molecule that contains the instructions an organism needs to develop, live and reproduce. These instructions are found inside every cell, and are passed down from parents to their children."

(Science, 2018)

Extracellular Matrix

"Extracellular matrix (ECM) is a structural scaffold that directs cell adhesion and migration, as well as regulating cellular growth, metabolism and differentiation signals."

(Sciencedirect.com, 2018d)

Fibroblast

"A type of cell found in connective tissue throughout the body that produces collagen and other proteins found in the extracellular (between cells) spaces"

(Shiel Jr., 2019)

Fibroblast shape

"Fibroblasts are large, flat, elongated (spindle-shaped) cells possessing processes extending out from the ends of the cell body. The cell nucleus is flat and oval."

(Encyclopedia Britannica, 2018)

Haute couture

"The term haute couture is a designation protected by law and "only those companies mentioned on the list drawn up each year by a commission domiciled at the Ministry for Industry are entitled to avail themselves thereof," to quote the Syndical Chamber for Haute Couture. The main criteria, set forth in 1945 and updated in 1992, are as follows: to employ a minimum of fifteen people at the workshops, to present to the press in Paris each season (spring/summer and autumn/winter) a collection of at least thirty-five runs consisting of models for daytime wear and evening wear."

(Apparelsearch.com, 2018b)

HGF1 Human Gingival Fibroblast

"Gingival fibroblasts are the major constituents of gingival tissue and play a key role in their maintenance."

(Sciencellonline.com, 2018)

Gingival

"Of or relating to the gums."

(www.dictionary.com, 2018)

Human Osteoblast

"Osteoblasts are bone forming cells. Of the three types of bone cells, they are the ones that produce the matrix that makes up bone. The *matrix*, or organic material, includes molecules such as collagen protein fibres, which give bone its flexibility, and calcium (Ca2+) and phosphate (PO4-) ions, which give bone its rigidity. Osteoblasts make and package the matrix molecules for release into the extracellular environment. Once released, the molecules in the matrix react with each other to form a rigid yet flexible bone tissue called *osteoid* that eventually hardens to form bone."

(Study.com, 2018)

GFP Green Fluorescent Protein

"Green fluorescent protein is a protein that glows green under fluorescent light. Found naturally in the jellyfish Aequorea victoria, GFP fluoresces green when exposed to blue light. GFP has been much used in molecular and cell biology research."

(MedicineNet, 2018)

Human Tissue Act

"The Human Tissue Act covers England, Wales and Northern Ireland. It established the Human Tissue Authority to regulate activities concerning the removal, storage, use and disposal of human tissue. Consent is the fundamental principle of the legislation and underpins the lawful removal, storage and use of body parts, organs and tissue. Different consent requirements apply when dealing with tissue from the deceased and the living."

(Hta.gov.uk, 2018)

Implant

"Insert or fix (tissue or an artificial object) in a person's body, especially by surgery."

(Oxford Dictionaries, English, 2018)

In vitro

"In vitro comes from the Latin term "in glass." The term refers to studies of biological properties that are done in a test tube (i.e. in a glass vessel) rather than in a human or animal."

(Verywell Health, 2018)

Mammalian Cells

"Cells from mammals"

(Regenerativemedicine.net, 2018a)

Morphology

"Study of the shape and visual appearance of cells, tissues and organs."

(Regenerativemedicine.net, 2018b)

Orientation

"The angle or position of an object, or the direction in which it is facing."

(Ldoceonline.com, 2018)

Phase Contrast Imaging

"Phase contrast imaging takes advantage of the fact that different materials have different refractive indices. This produces a phase shift in the X-rays passing through the sample. By placing the imaging detector at a specific distance from the sample, interference between waves can be used to enhance contrast in the image."

(Source, 2018)

Proliferate

“To increase greatly in number or amount - usually quickly.”

(Dictionary.cambridge.org, 2018a)

Protocol

“A detailed plan of a scientific or medical experiment, treatment, or procedure.”

(Merriam-webster.com, 2018a)

Prototype

“The first example of something, such as a machine or other industrial product, from which all later forms are developed.”

(Dictionary.cambridge.org, 2018b)

Regenerative medicine

“Clinical procedures that aim to repair damaged tissue or organs, most often by using tissue engineered scaffolds and stem cells to replace cells and tissues damaged by aging and by disease. In some cases, medical devices are part of the therapeutic procedure.”

(Regenerativemedicine.net, 2018c)

Scaffold

“In the context of engineered tissue, a scaffold is a material that can be formed in the shape of tissue that needs to be replaced (as an example a rotator cuff). The scaffold can be biologically derived or a synthesized material. The scaffold material must be biologically compatible for human implantation. The scaffold is typically impregnated (seeded) with a patient’s cells before implantation.”

(Regenerativemedicine.net, 2018d)

Seeding

“Implanted or impregnated as in seeding a scaffold with stem cells.”

(Regenerativemedicine.net, 2018e)

Speculative Design

Is a term coined by Anthony Dunne and Fiona Raby, to describe work that looks "to create spaces for discussion and debate about alternative ways of being, and to inspire and encourage people's imaginations to flow freely. Design speculations can act as a catalyst for collectively redefining our relationship to reality."

(Duune and Raby, 2013, p. 2)

Synthetic biology

“Synthetic biology aims to design and engineer biologically based parts, novel devices and systems as well as redesigning existing, natural biological systems.”

(Synbicite.com, 2018)

Tacit knowledge

“Tacit knowledge is knowledge that is hard to quantify or pass from one person to another through verbal or written communication. Tacit knowledge includes skills like speaking a language, playing a music instrument or carving a figurine out of a piece of wood, along with basic life skills such as facial recognition.”

(HRZone, 2019)

Tissue Culture

“The process or technique of making body tissue grow in a culture medium outside the organism.”

(Merriam-webster.com, 2018b)

Tissue Engineering

“Tissue engineering can be defined as the use of a combination of cells, engineering materials, and suitable biochemical factors to improve or replace biological functions in an effort to improve clinical procedures for the repair of damaged tissues and organs. The first definition of tissue engineering is attributed to Drs. Langer and Vacanti who stated it to be "an interdisciplinary field that applies the principles of engineering and life sciences toward the development of biological substitutes that restore, maintain, or improve tissue function or a whole organ".

(Regenerativemedicine.net, 2018f)

APPENDIX 2

CONSTRUCTED EXPERIMENTS

CONSTRUCTED EXPERIMENTS 1 & 2

CONSTRUCT
verb
past tense: **constructed; past participle: constructed**

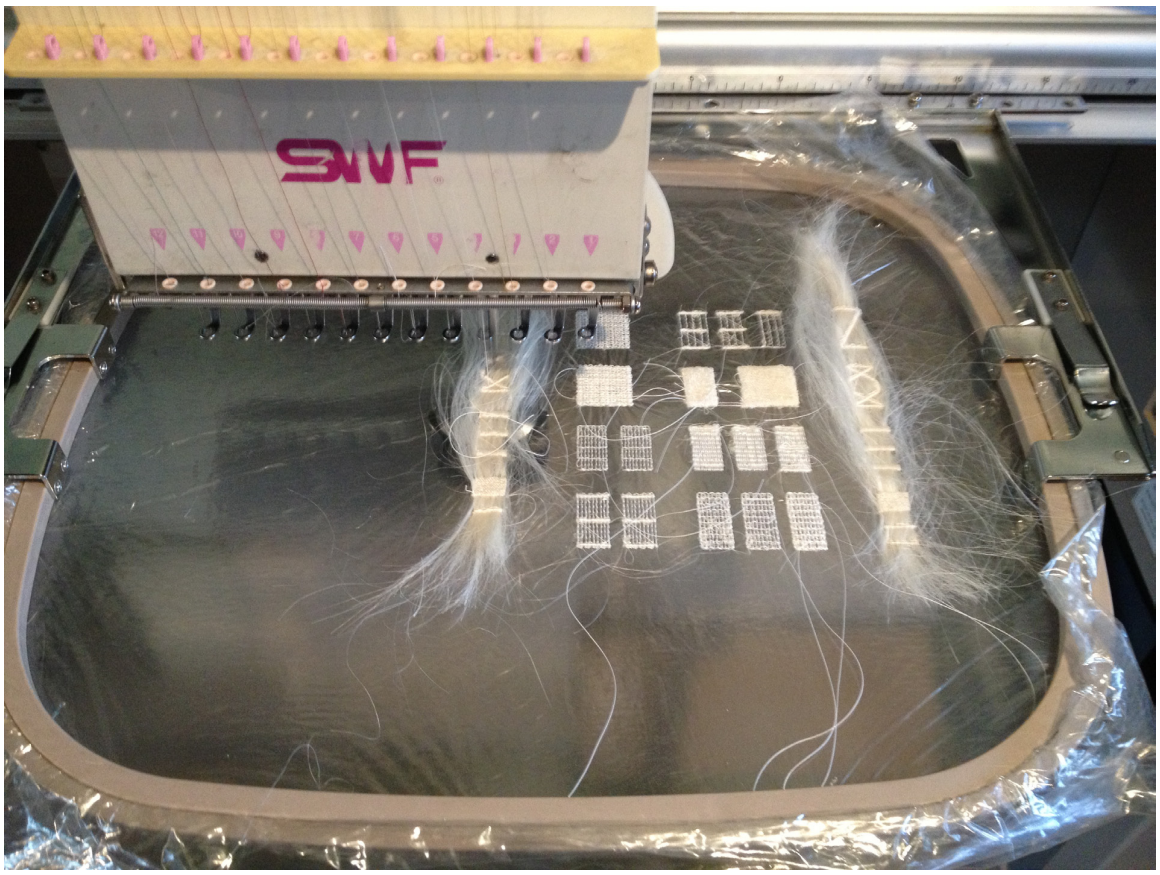
- **build or make (something, typically a building, road, or machine).**
  "a company that constructs oil rigs"
  synonyms: *build, erect, put up, set up, raise, establish, assemble, manufacture, fabricate, form, fashion, contrive, create, make*
  antonyms: *demolish*

- **form (an idea or theory) by bringing together various conceptual elements.**
  "poetics should construct a theory of literary discourse"
  synonyms: *formulate, form, put together*

CONSTRUCT LAB SERIES:

The overall aim of this series of experiments is to develop a material and technique library unique to a textile sampling process within a tissue engineering laboratory.

The experiments are intially looking to understand how the structure of a scaffold affects how cells orientate themselves. The goal is to continue to move forward with more complex set ups such as exploring using different stitches could allow for the control of several cell types in one culture.



Various silk scaffolds being produced on a digital emroidery machine, onto dissolvable fabric.

Scaffolds ready to be autoclaved for sterilisation - they are sterilised in water to have the added benefit of washing out backing fabric.

CONSTRUCTED EXPERIMENT 1

Pearsalls Limited

PRODUCT INFORMATION

Silk Braided SUTURES

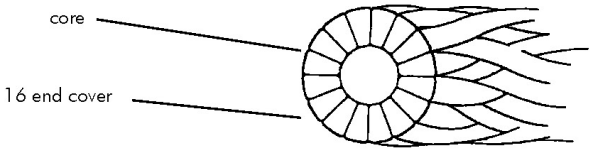
PRODUCT

Pearsalls Silk Sutures have been developed over many years to achieve the greatest tensile strength whilst maintaining a consistent diameter within the limits of the European or US Pharmacopoeia.

By application of the most modern textile processing techniques Pearsalls convert a traditional natural filament into a suture material for modern surgery. Black silk can be supplied dyed with the traditional Sulphol black, meeting European Pharmacopoeia requirements. Alternatively it is available dyed Logwood black, complying with the US and European Pharmacopoeia standards. It is also available in a natural Ivory colour.

CONSTRUCTION

Individual filaments of the highest quality Chinese silk are specially treated to give good handling properties. The filaments are then twisted together and braided. The braid is made up of the core of twisted silk around which a cover is plaited from 8, 12 or 16 silk threads. Special processes are then applied to ensure regularity of diameter, surface smoothness and the best extension for good knotting characteristics.



PHYSICAL PROPERTIES

EP Metric Size	USP Size	Standard Diameter (mm)	Tensile Strength		Extension at Break (Note 3) %	Sales Unit (m/reel)
			Standard Knot Pull (Note 1) (kg)	Pearsalls Average Knot Pull (Note 2) (kg)		
0.5	7/0	.050-.069	0.14	0.17	8.01	1000
0.7	6/0	.050-.069	0.25	0.37	9.23	1000
1	5/0	.100-.149	0.50	0.63	7.77	3000
1.5	4/0	.150-.199	0.75	1.10	8.00	3000
2	3/0	.200-.249	1.20	1.55	10.24	3000
2.5	-	.250-.299	1.40	1.94	10.39	2000
3	2/0	.300-.349	1.80	2.62	12.42	2000
3.5	1/0	.350-.399	2.70	3.80	10.63	1000
4	1	.400-.499	3.40	4.93	13.15	1000
5	2	.500-.599	4.40	7.05	13.48	500
6	3+4	.600-.699	6.10	8.41	16.21	500
7	5	.700-.799	7.70	12.23	17.30	250
8	6	.800-.899	9.10	13.56	17.45	250

NOTES

1. Standard knot pull tensile strength is as stated in the latest editions of European Pharmacopoeia and US Pharmacopoeia.
2. for non-absorbable sutures Class 1 – plus 25% for non-sterile sutures.
3. Pearsalls knot pull test is made with a simple knot.
4. Extension is the elongation of the material at break or rupture in a straight pull test expressed as a percentage of the original length.

Pearsalls Limited

PRODUCT INFORMATION

Silk suture thread material data sheet

MATERIALS

Silk	Protein fibre from filaments spun by the silkworm – Bombyx Mori L.
Colours	Sulphol Black. Logwood Black. Natural Ivory
Dyestuffs	Black CI 53185 Sulphol Black 1 (EP Vol III) Formulae (Empirical only) – $C_{24}H_{16}N_6O_8S_7$.
	Logwood Black CI 75290. Natural Tinctorial Wood Extract obtained from Haematoxylon Campechianum. Conforms to US Code of Federal Regulations 21 CFR 73.1410.
Finishes	Wax – 100% Pure Beeswax BP.
	Silicone – Nusil Med 2174 Silicone Elastomer.
	Uncoated

SUPPLY PACKAGES

On large reels containing up to 3,000 metres. On small reels for hospital use with 22m or 90m and supplied in boxes of 10 reels.

COATINGS

Silicone and Wax coatings are available from stock in Taunton. Uncoated sutures are made to special order.

BATCH NUMBERING

All reels are marked with a batch number which identifies the date of production, materials used and details of Quality Control tests. Records of dispatches of each batch are maintained so that recall of individual batches can be effected in accordance with Good Manufacturing Practice.

QUALITY

Pearsalls Ltd quality system conforms to ISO 9001 2000. We are audited twice a year to ensure that we continue to meet the highest standards that can be achieved. Our notified body is SGS Yarsley. Certificates of conformity which show the test results obtained by Quality our Control Department are supplied with every batch or lot in a shipment.

GOOD MANUFACTURING PRACTISE

Pearsalls Sutures have introduced FDA Good Manufacturing Practice into all aspects of production and quality control. These procedures include the maintenance of detailed batch records, control of processes and procedure, staff training and a controlled production environment.

U.S. FOOD AND DRUG ADMINISTRATION (F.D.A.)

Pearsalls sutures are registered with the United States Food and Drug Administration as a manufacturer of non-sterile suture materials. Registration No. 8010203-6B

INTERNATIONAL STANDARDS

The products of Pearsalls sutures are designed and inspected to comply with the latest editions of the European Pharmacopoeia and United States Pharmacopoeia.

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http://www.pearsalls.co.uk

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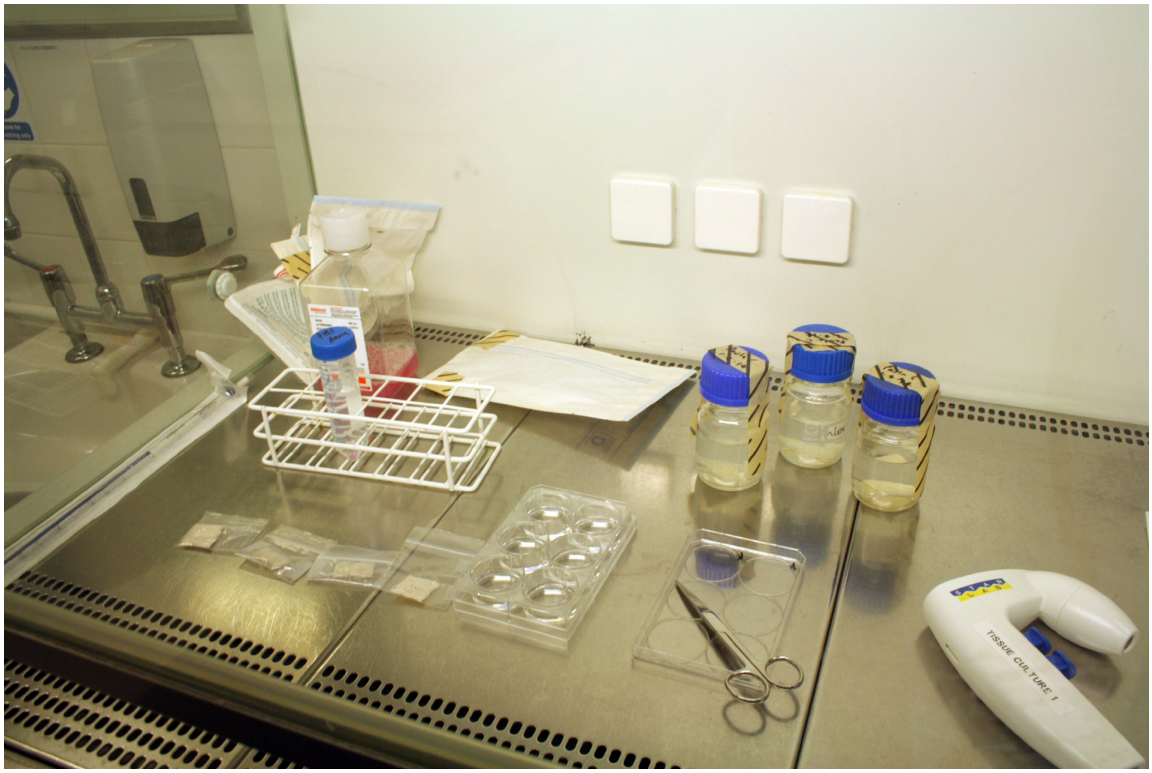
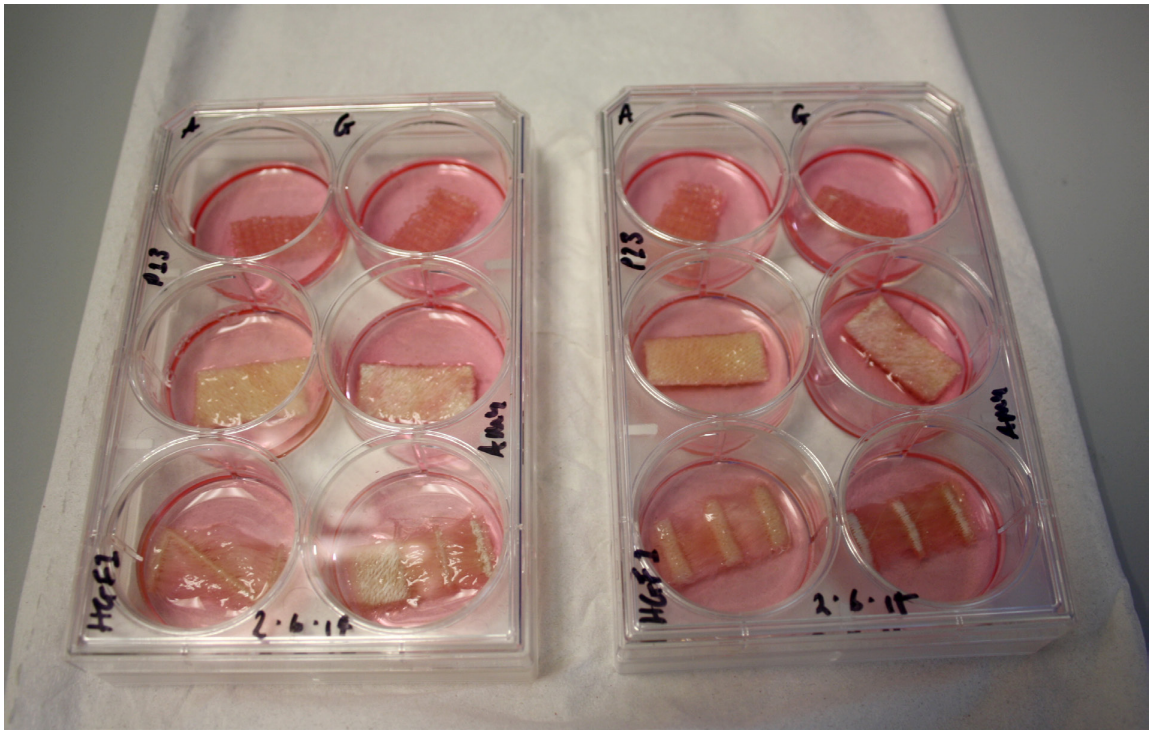
SEEDING SCAFFOLDS



Working in the tissue culture hood to prepare and then seed the different scaffolds



The above image shows the seeded scaffolds in culture media ready to go into the incubator.

PROTOCOL

AIMS

1. To determine efficiency of irradiation methods
2. To assess cell adherence, viability and orientation on the different test scaffolds.

STEPS

- Grow sufficient flasks of fibroblast cells to be able to seed all scaffolds
- Using 6 well plates place one each of scaffold type 1A, 1G, 5A, 5G, 11A & 11G (see figure 1) into two plates
- Trypsinize cells, count and microseed 1ml onto each scaffold
- Leave scaffolds for 4 hours and then add culture media
- After 24 hours use live and dead staining on each scaffold in plate 1 to acertain cell viability
- After 4 days use live and dead staining on each scaffold in plate 2 to acertain cell viability and oreintation

FIGURE 1

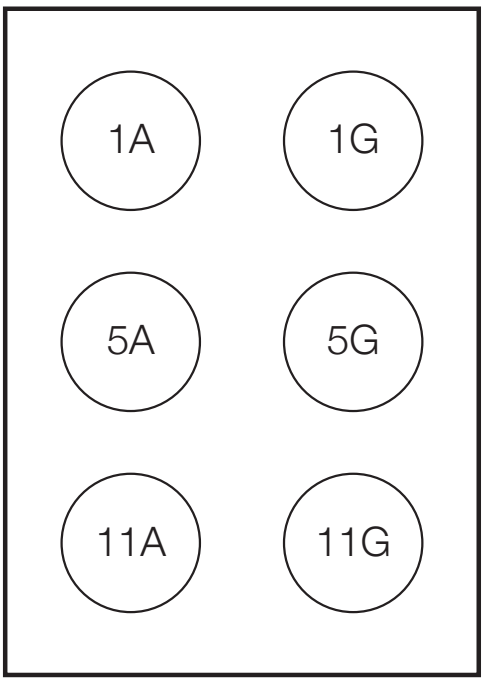


Plate 1
24 hrs culture

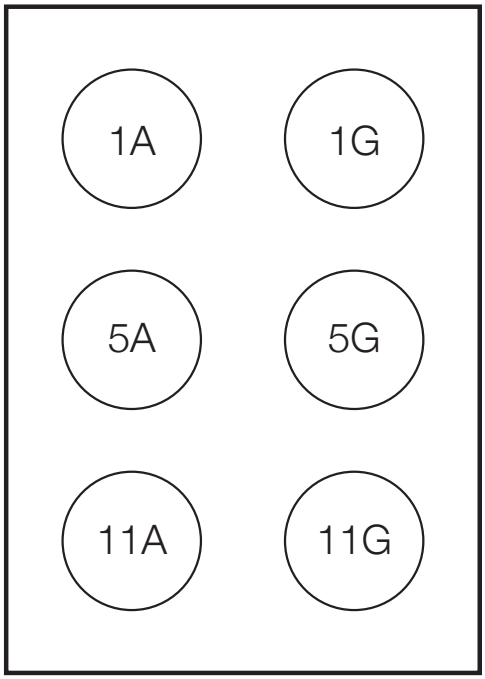
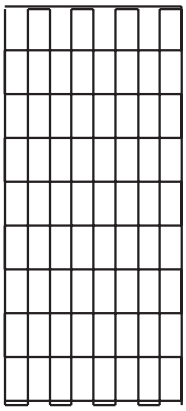


Plate 2
4 days culture

KEY
A = Autoclaved G = Gamma Irradiated No.s = Scaffold Type *(see next page)*

SILK SUTURE THREAD SCAFFOLD DESIGN

1



SCAFFOLD 1

Size:
13mm x 29mm

Stitch Type:
Running stitch

Structure:
Single layer grid

5

SCAFFOLD 5

Size:
14mm x 25mm

Stitch Type:
Fill stitch

Structure:
Double layer of fill stitch - each layer stitched in a different diagonal direction

11

SCAFFOLD 11

Size:
14mm x 26mm

Stitch Type:
Satin stitch

Structure:
Loose silk fibres held in place by satin stitched bands

Live/Dead Stain (use 1 x 10^5 cells per ml)

Live/Dead Viability/Cytotoxicity Kit (L-3224) from invitrogen

Kit contains
4mM Calcein AM in anhydrous DMSO – Irritating to eyes, respiratory system and skin
2mM Ethidium homodimer-1 in DMSO/water – Irritating to eyes, respiratory system and skin.

Kit stored at –20^{0}C (freezer 1, shelf 6)

Cells should be grown on thermanox disks.

Add 1µl of each component to 1ml of ~~Phenol Free complete DMEM or~~ PBS.

Add enough of the above solution to cover the disks.

Incubate in the CO_2 incubator ~~for 1 hour~~. 10 minutes may be enough.

Place the thermanox disk on a glass slide and cover with a cover slip. (This is to stop evaporation of fluid. View the disk under a fluorescent microscope.

If solid material need to flip over.

Green – Live cells
Red – dead cells

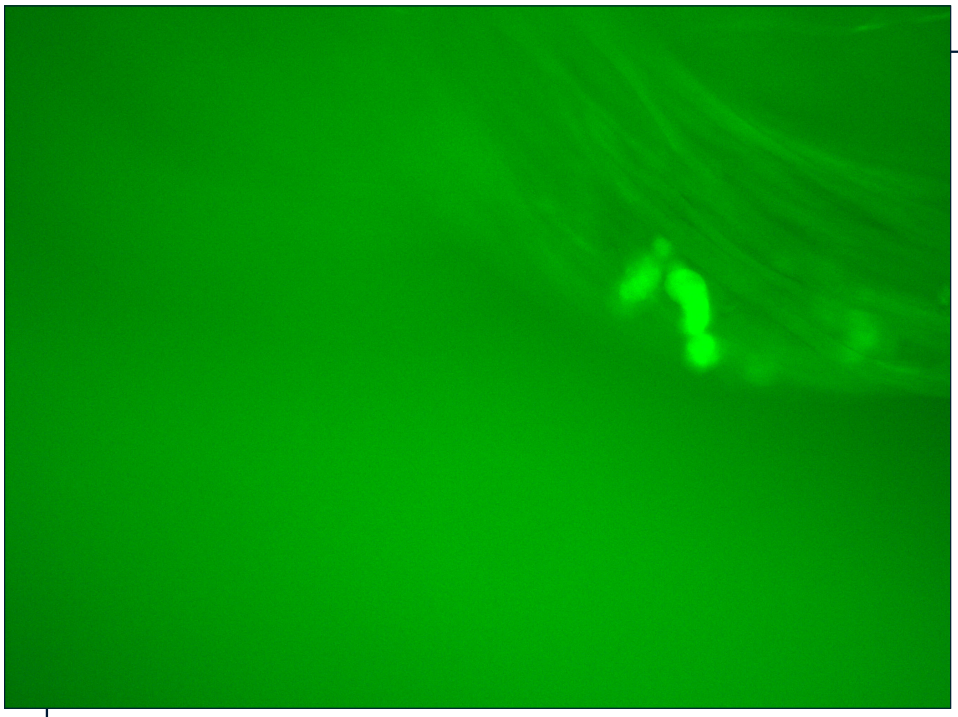
Non Kit Method
2µl 1mM Calcein AM (10µl aliquots)
1µl Ethidium Bromide (from Kit)
Put into 1ml of ~~Phenol Red Free Media~~ or PBS.

Pre Book Microscope - New tissue lab.

CONSTRUCTED EXPERIMENT 1

24 hr
LIVE DEAD

RESULTS



Scaffold no.:
A 1

Cell type:
HGF1

Passage no.:
P13

Magnification:
x200

LIVE

1

2

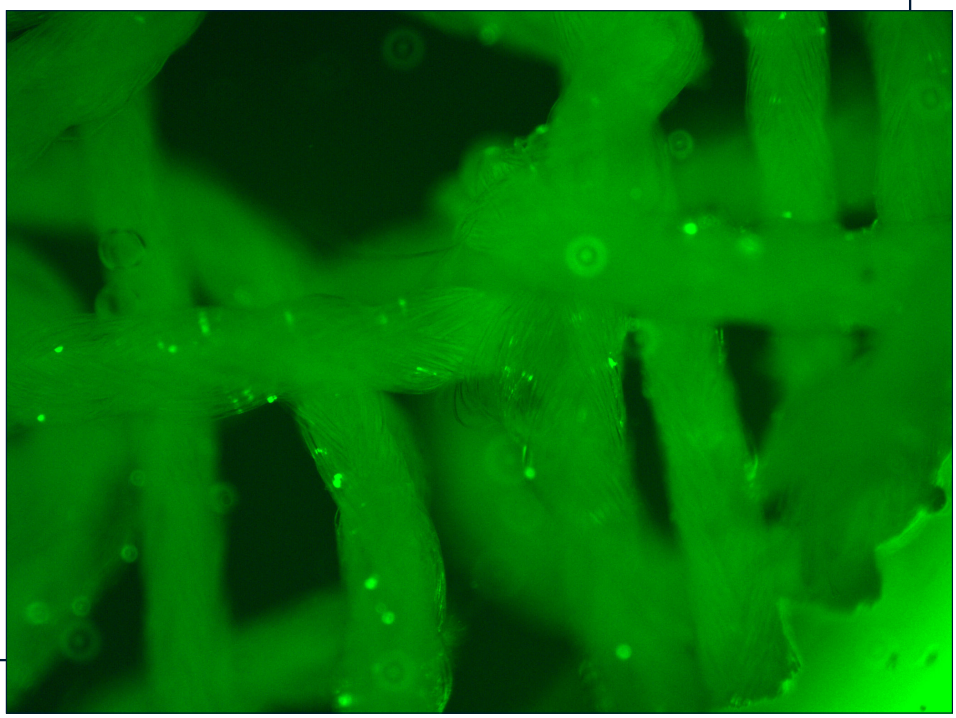
Scaffold no.:
G 1

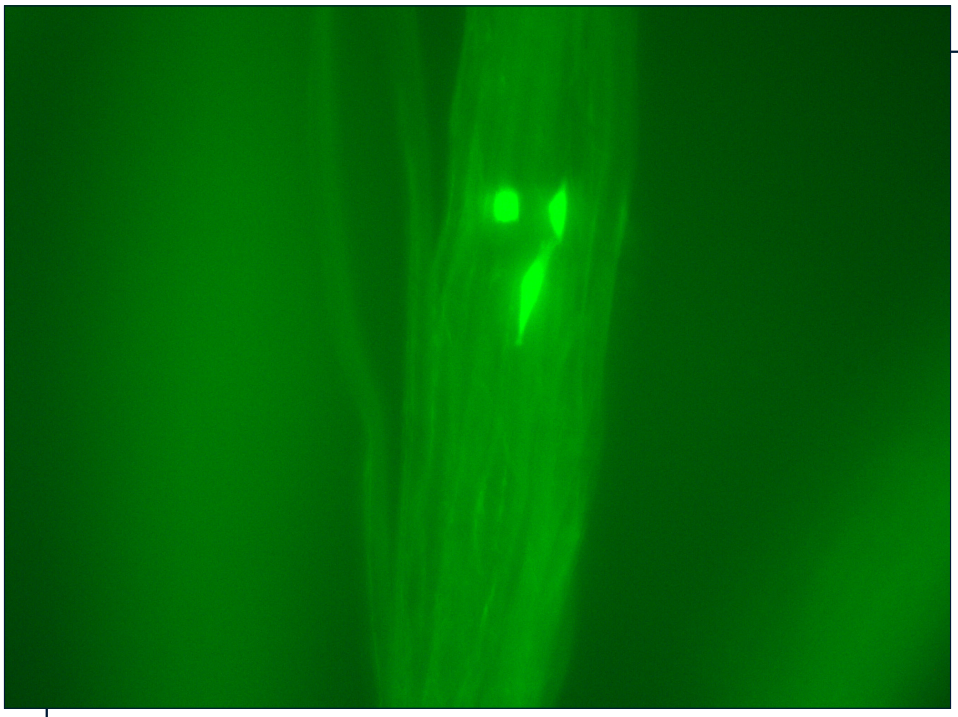
Cell type:
HGF1

Passage no.:
P13

Magnification:
x40

LIVE





Scaffold no.:
G 3

Cell type:
HGF1

Passage no.:
P13

Magnification:
x100

LIVE

3

4

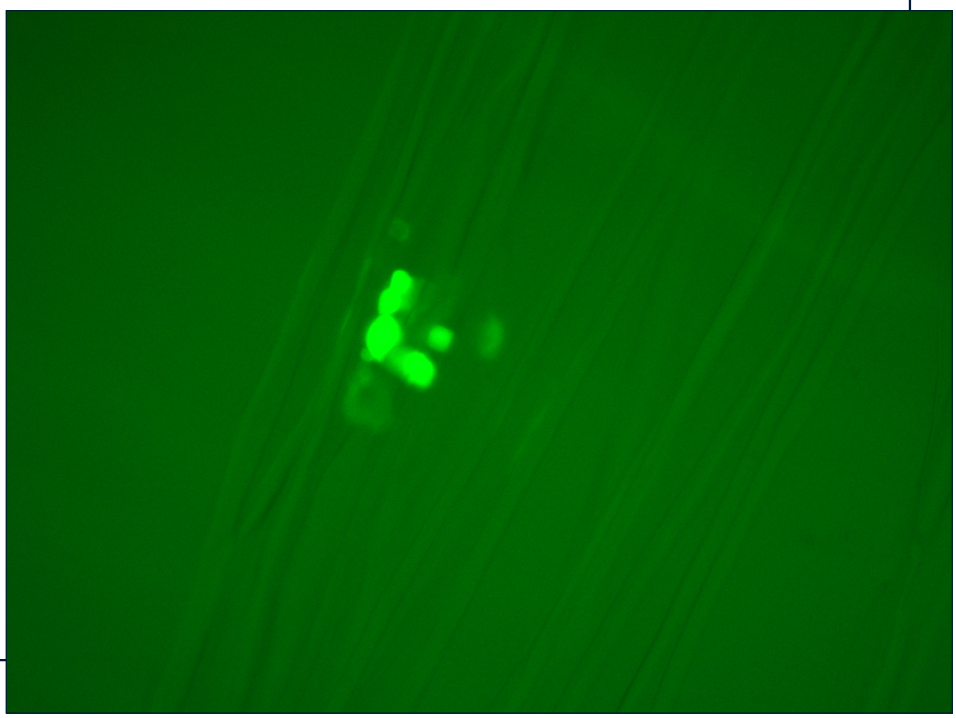
Scaffold no.:
A 3

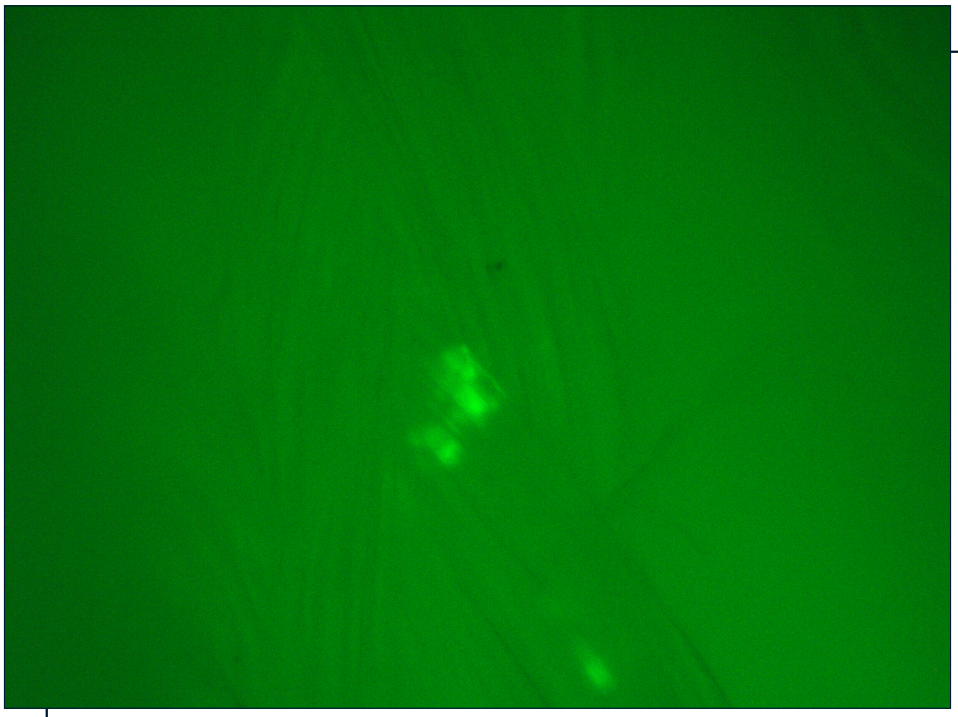
Cell type:
HGF1

Passage no.:
P13

Magnification:
x200

LIVE





Scaffold no.:
A 2

Cell type:
HGF1

Passage no.:
P13

Magnification:
x200

LIVE

5

6

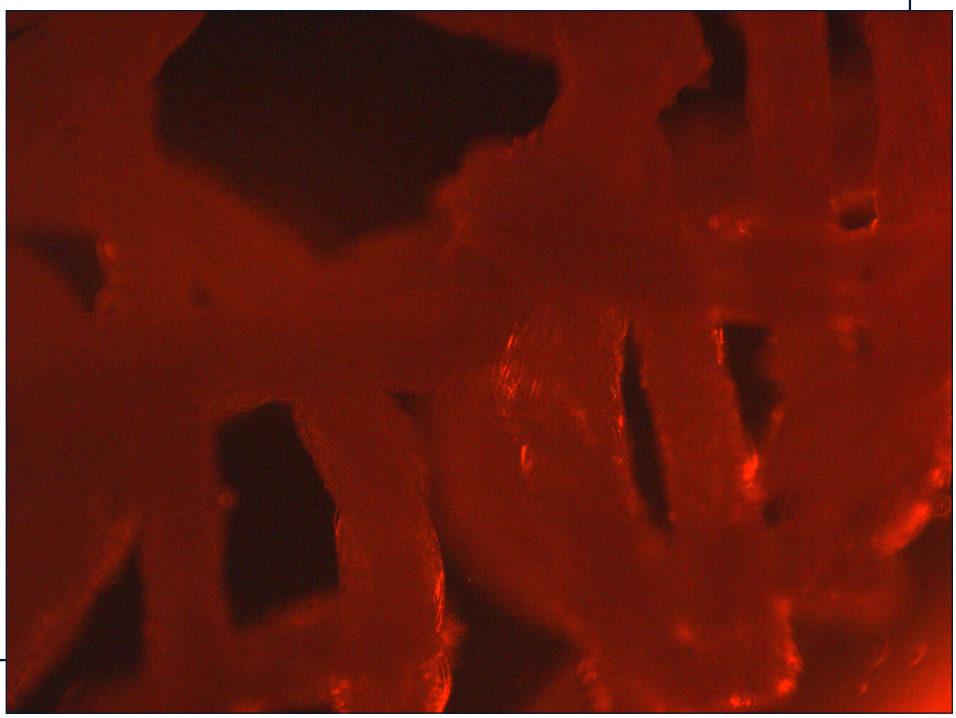
Scaffold no.:
G 1

Cell type:
HGF1

Passage no.:
P13

Magnification:
x40

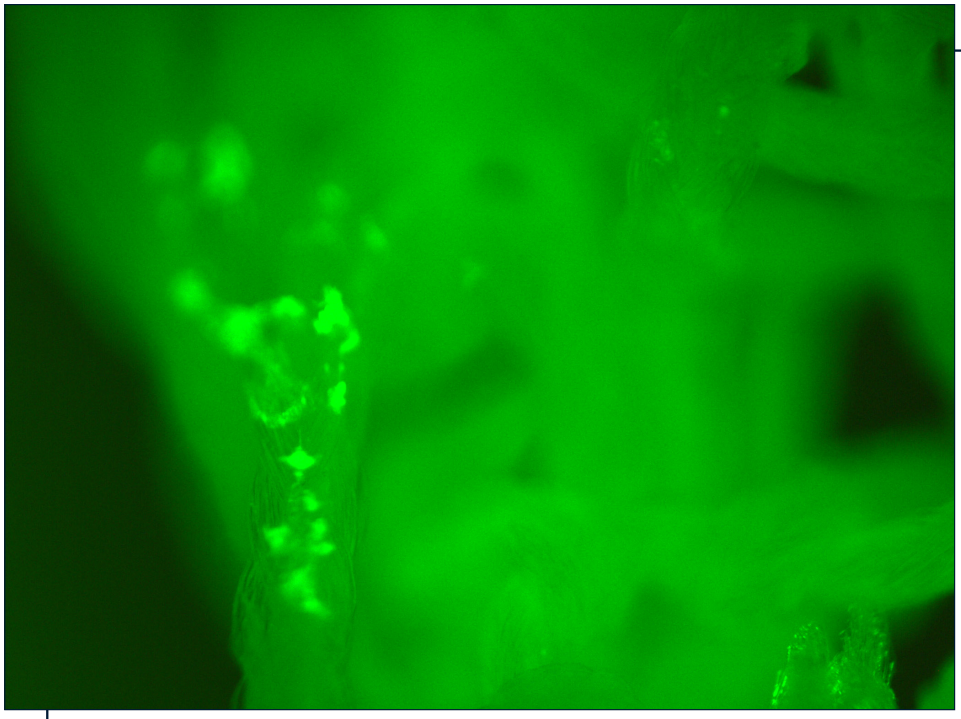
DEAD



CONSTRUCTED EXPERIMENT 1

4 day
LIVE DEAD

RESULTS



Scaffold no.:
A 1

Cell type:
HGF1

Passage no.:
P13

Magnification:
x40

LIVE

1

2

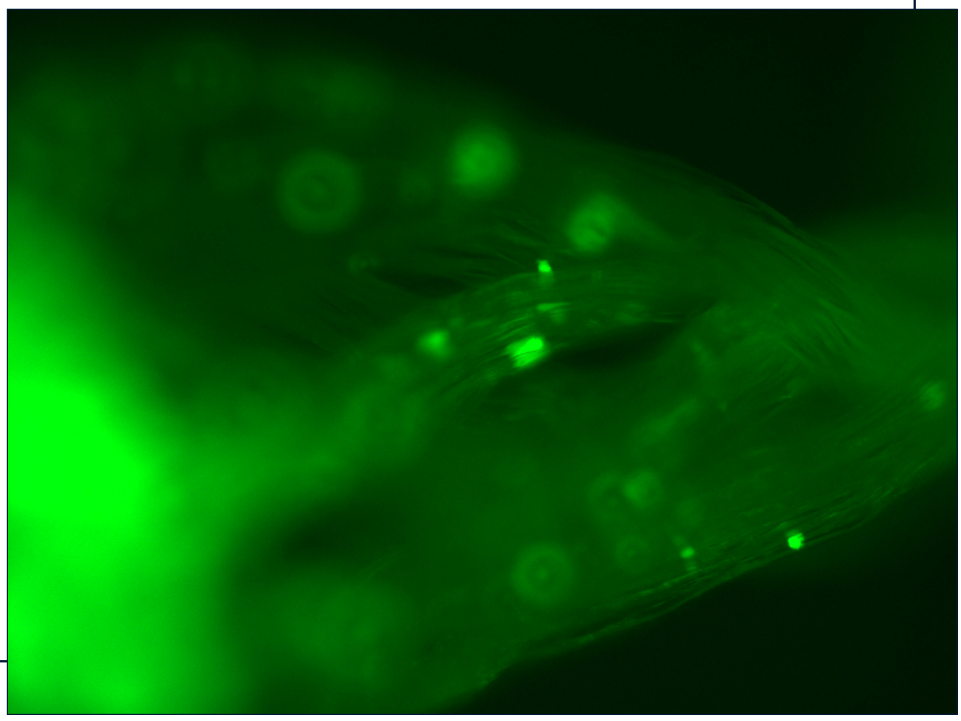
Scaffold no.:
G 1

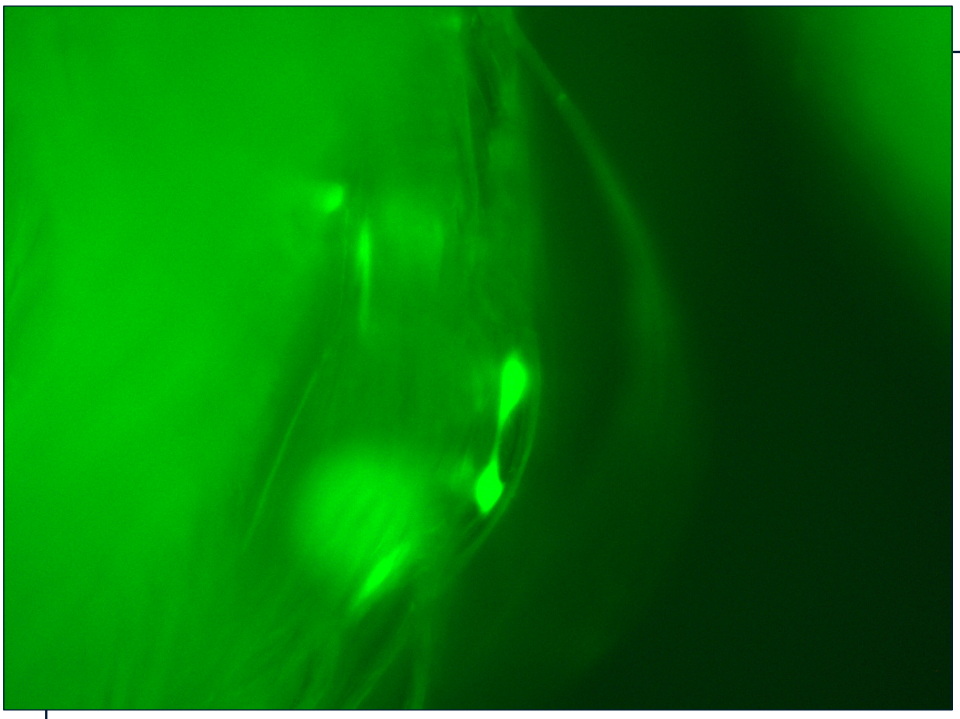
Cell type:
HGF1

Passage no.:
P13

Magnification:
x40

LIVE





Scaffold no.:
A 2

Cell type:
HGF1

Passage no.:
P13

Magnification:
x100

LIVE

3

4

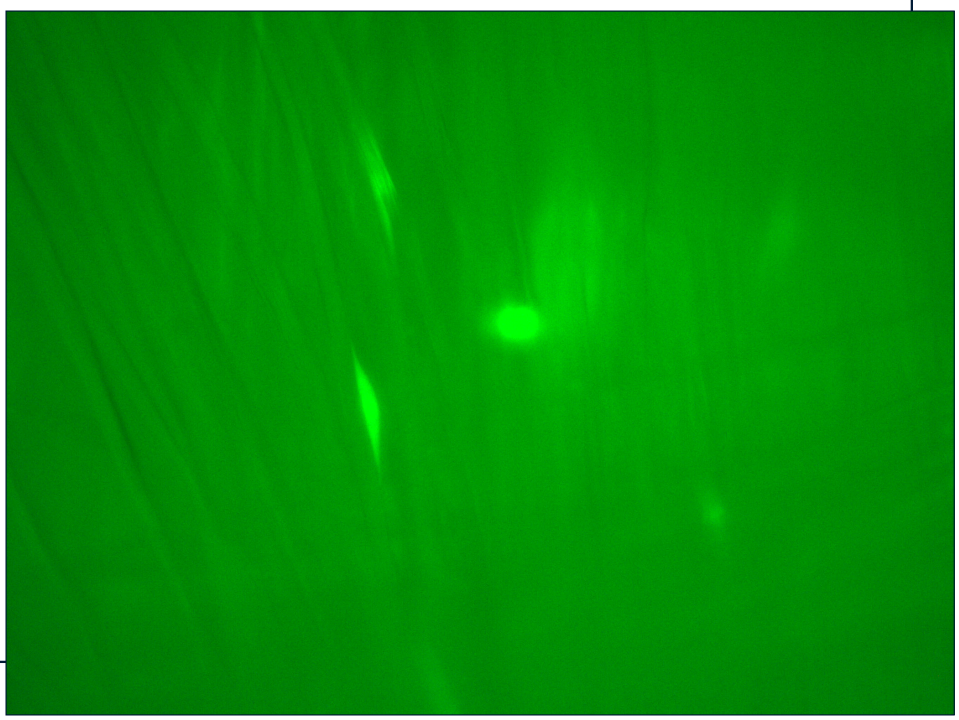
Scaffold no.:
A 3

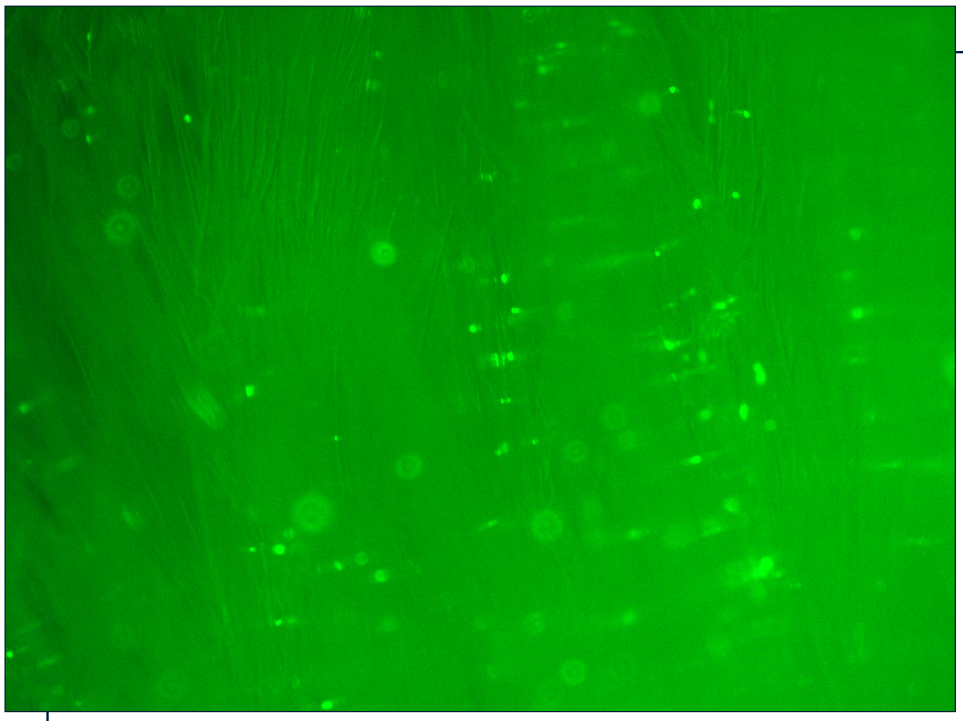
Cell type:
HGF1

Passage no.:
P13

Magnification:
x200

LIVE





Scaffold no.:
A 3

Cell type:
HGF1

Passage no.:
P13

Magnification:
x40

LIVE

5

6

Scaffold no.:
A 1

Cell type:
HGF1

Passage no.:
P13

Magnification:
x40

DEAD

RESULTS

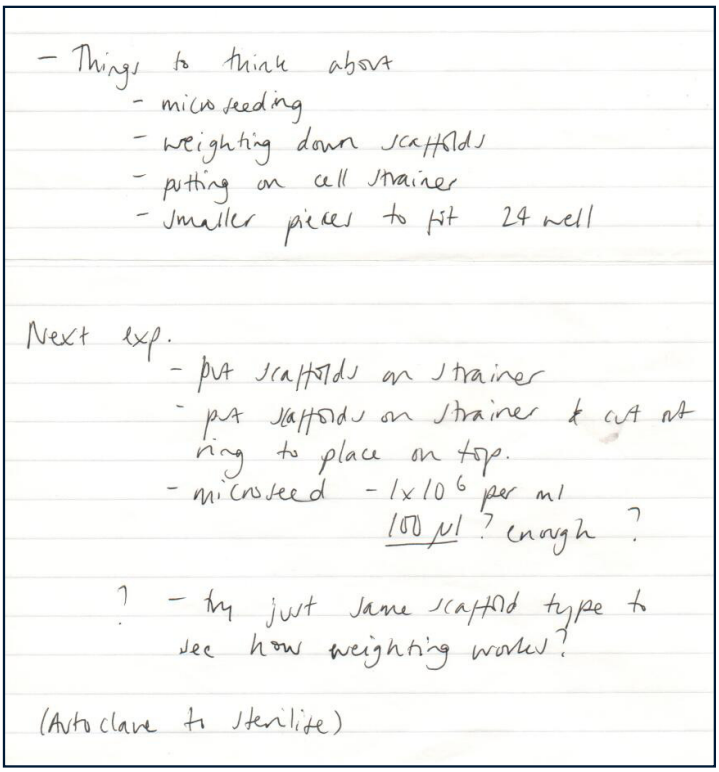
FINDINGS & ISSUES

1. The cells seemed to attach to all scaffold types, with very few dead cells showing up at 24 hrs or 4 days imaging. Also due to the fact that the material needed 2ml of media the scaffolds were only seeded at half the ideal concentration for live dead imaging
2. As the scaffolds floated it seems that quite a number of cells fell through the scaffolds onto the bottom of the well
3. Due to the scaffolds floating some of the cells were not covered in media and therefore died, in particular scaffold type 5

NEXT STEPS

- The scaffolds do not need to be so big so I need to look at working in a 24 well plate (to reduce the number of flasks of cells I need)
- Look at weighting the scaffolds down to stop them floating
- Use microseeding to deliver highly concentrated amounts of cells onto the material.
- Use just one stitch type for the next experiment to develop the most effect protocol, before looking to explore varying stitch types.

Notes on next steps



CONSTRUCTED EXPERIMENT 2

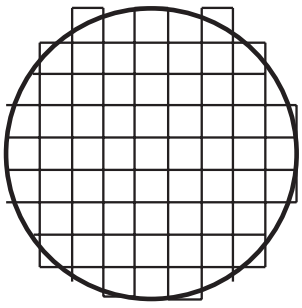
PROTOCOL

AIMS

1. To determine the best concentration of cells to microseed
2. To assess cell adherence, viability and orientation on the scaffold

STEPS

- Grow sufficient flasks of fibroblast cells to be able to seed all scaffolds
- Using two 24 well plates place four scaffolds into each the plate
- Trypsinize cells, count and microseed two of the scaffolds in each plate with 100 microlitres of cells at 1x 10^5 and the other two scaffolds with 50 microlitres at 1x 10^5
- Leave scaffolds for an hour and then add 900 microlitres of culture media
- After 24 hours use live and dead staining on each scaffold in plate 1 to ascertain cell viability (for the stain use half the recommended amount to help combat the scaffold auto fluorescing)
- After 4 days use live and dead staining on each scaffold in plate 2 to ascertain cell viability and orientation (for the stain use half the recommended amount to help combat the scaffold auto fluorescing)



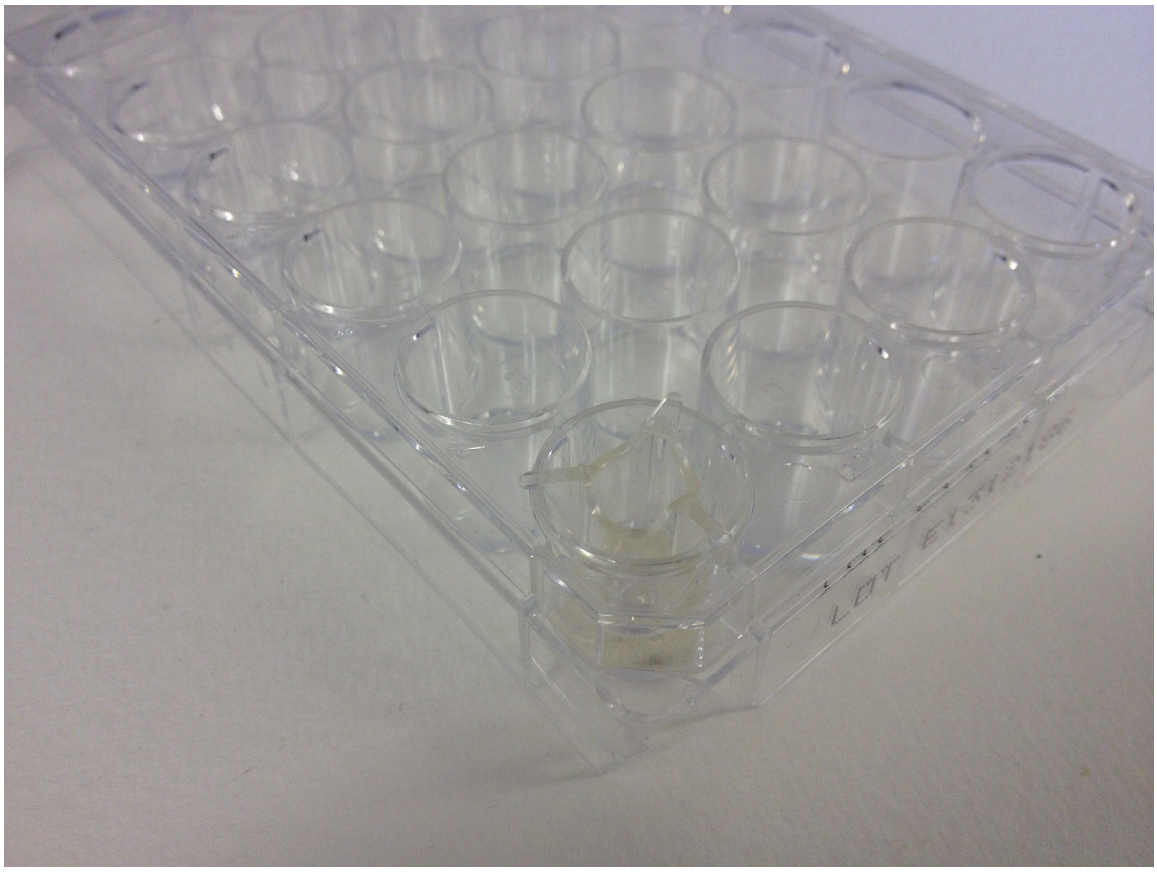
SCAFFOLD 13

This scaffold is designed to fit exactly into one of the 24 well plate dishes. It is much smaller than the scaffolds from experiment 1.

Size:
15mm diameter

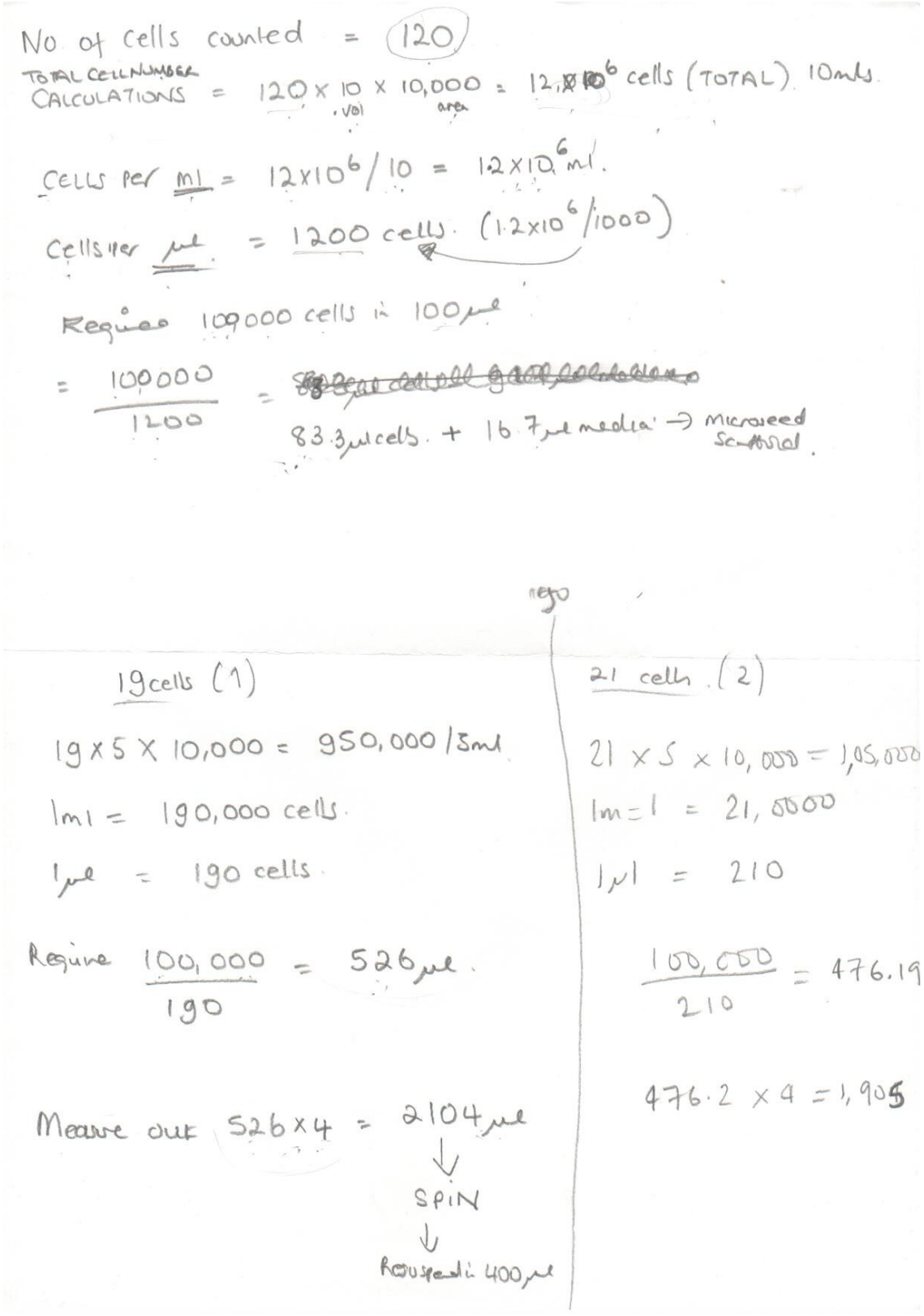
Stitch Type:
Running stitch, with satin stitch circle over the top

Structure:
Single layer grid

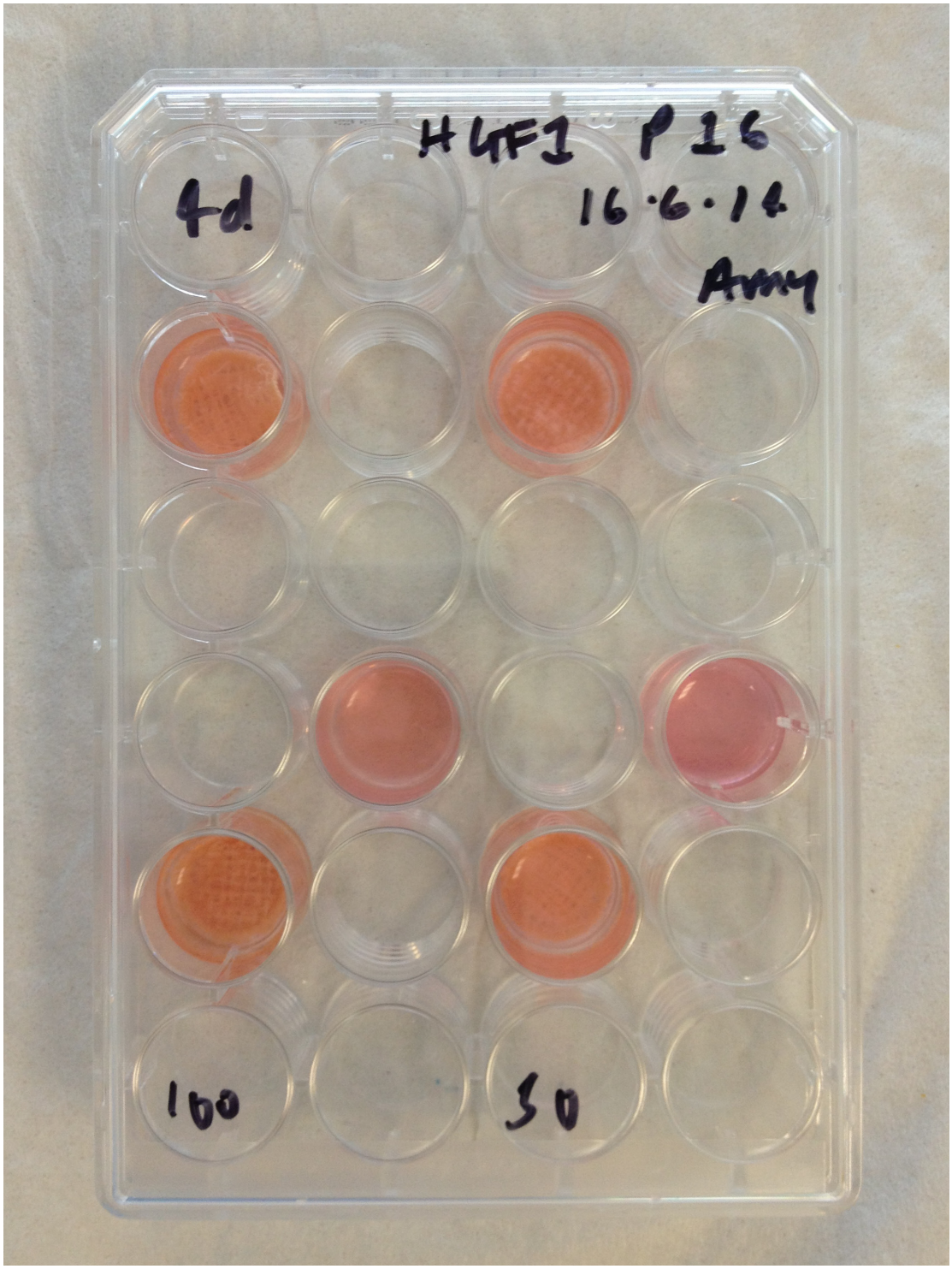


Due to the problem of the scaffolds floating in the culture dishes in experiment 1 we looked at different weighting options

This little piece of plastic is cell sieve - the idea was to push the mesh out and use it to sit on top of the scaffold. In the end it wasn't necessary but it opens up interesting ideas for how to contain cells in future experiments.



Maths = working out how much media to add to my cells to get the desired concentration for live/dead microseeding

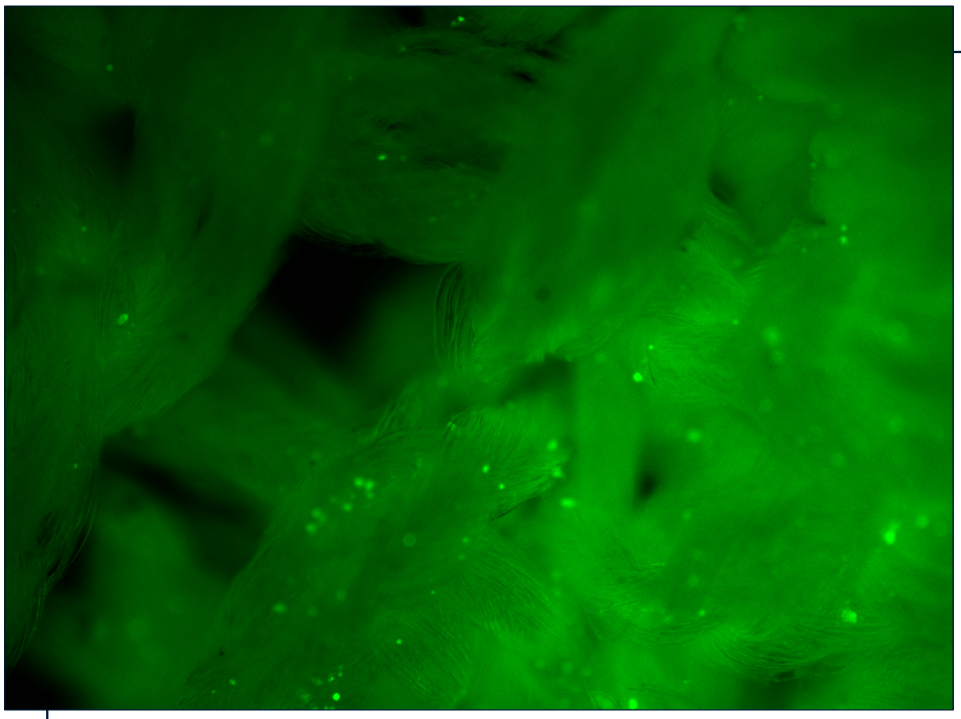


This is an image of 4 scaffolds - 2x seeded with cells at 100 microlitre concentration and x2 at 50 microlitre. This picture was taken after 4 days in the incubator

CONSTRUCTED EXPERIMENT 2

24 hr LIVE DEAD

RESULTS



Scaffold no.:
13

Microseed:
50 µL

Cell type:
HGF1

Passage no.:
P16

Magnification:
x40

LIVE

1

2

Scaffold no.:
13

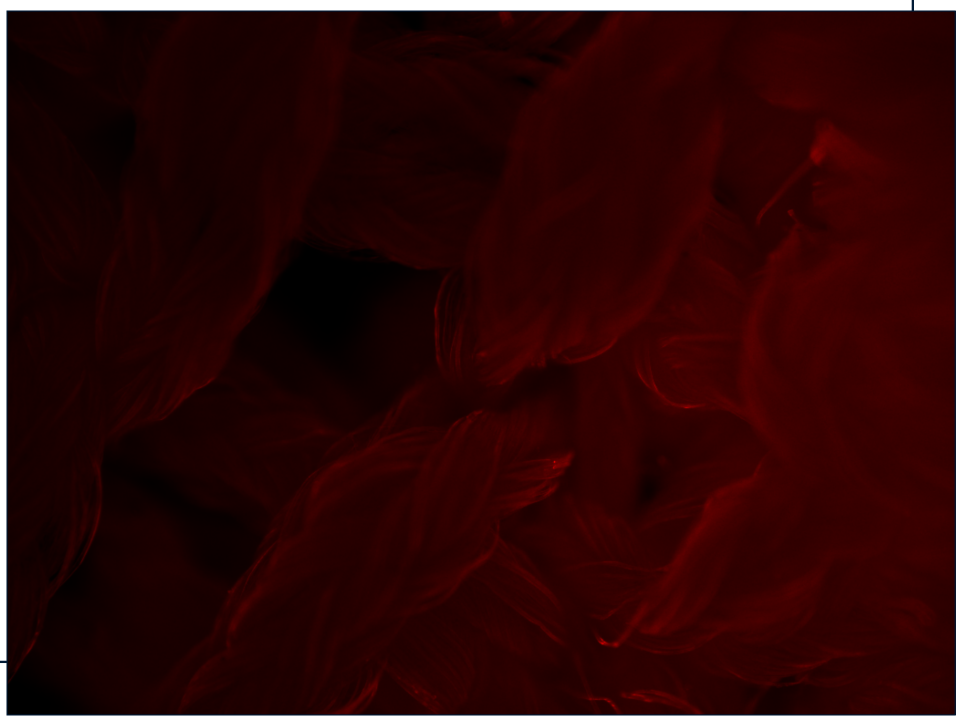
Microseed:
50 µL

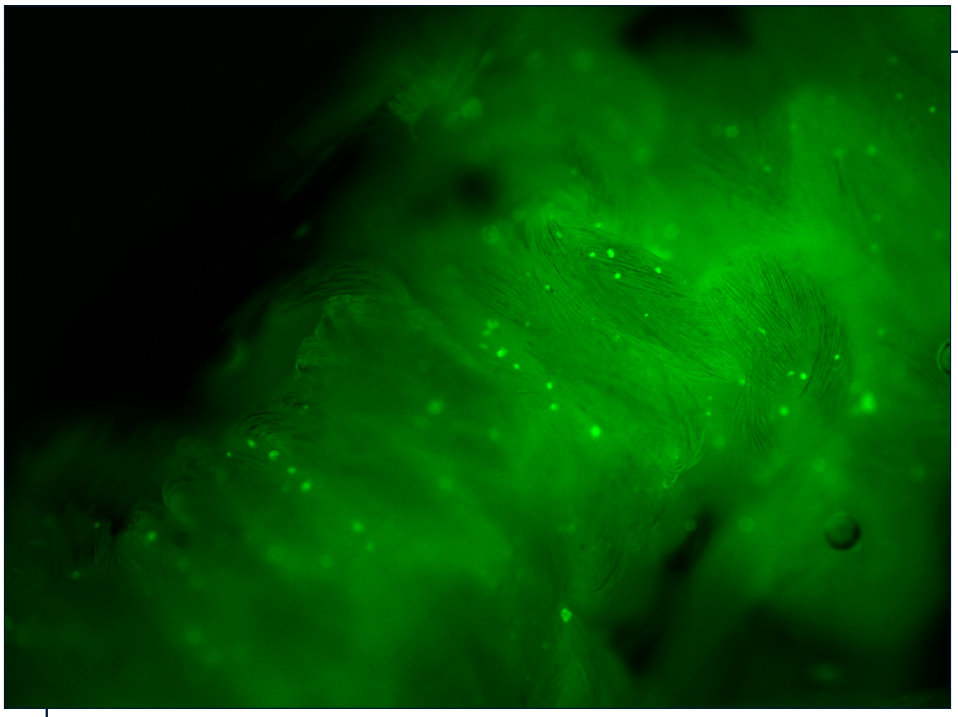
Cell type:
HGF1

Passage no.:
P16

Magnification:
x40

DEAD
(same image as above)





Scaffold no.:
13

Microseed:
100 µL

Cell type:
HGF1

Passage no.:
P16

Magnification:
x40

LIVE

3

4

Scaffold no.:
13

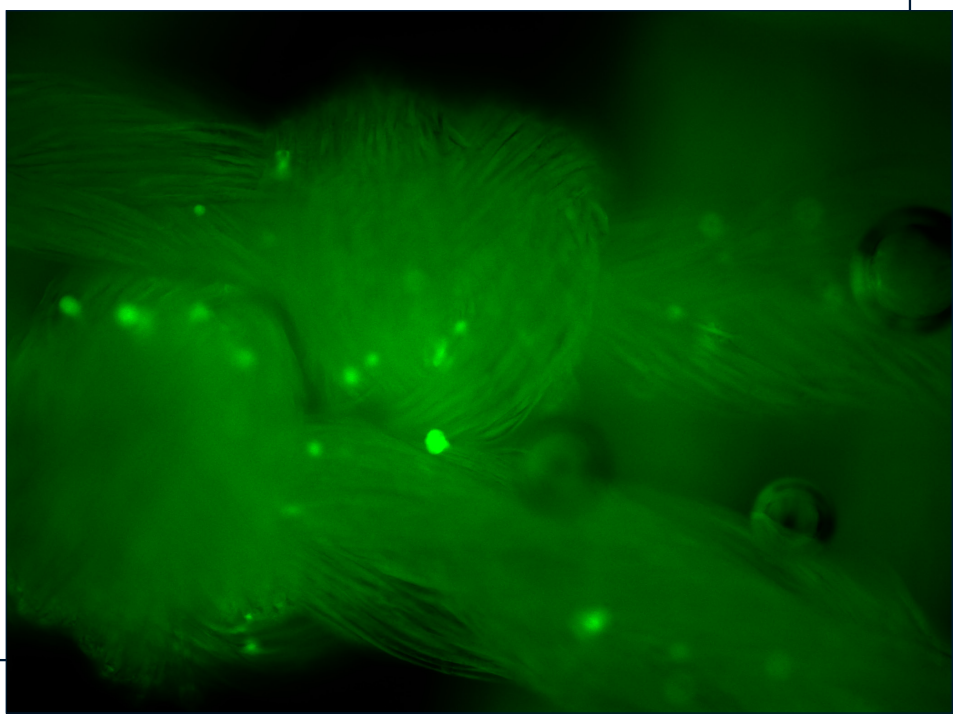
Microseed:
100 µL

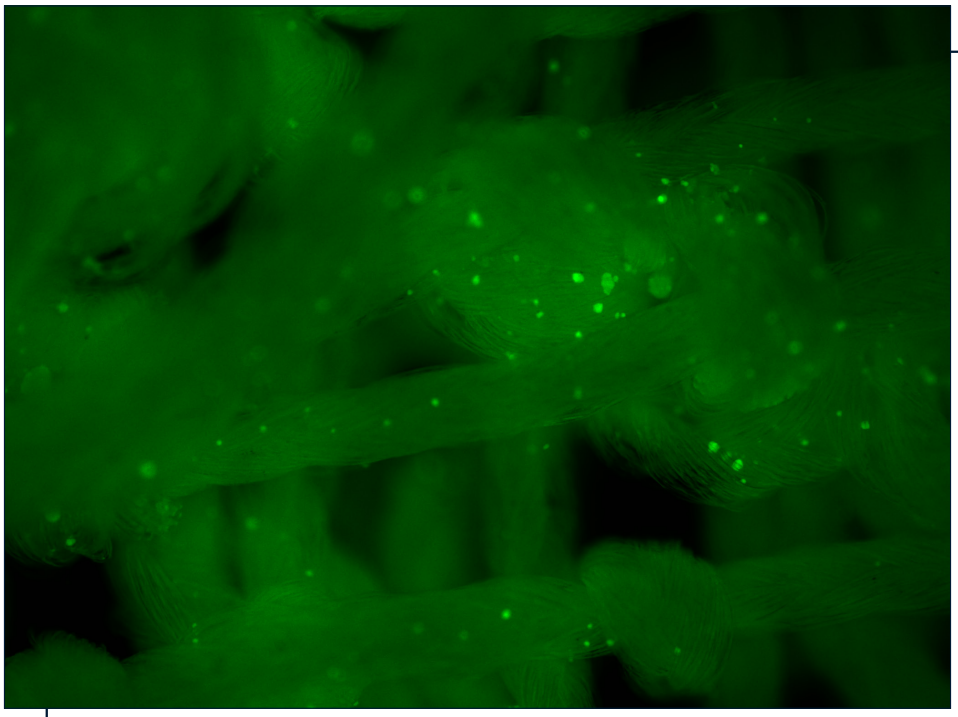
Cell type:
HGF1

Passage no.:
P16

Magnification:
x100

LIVE





Scaffold no.:
13

Microseed:
100 µL

Cell type:
HGF1

Passage no.:
P16

Magnification:
x40

LIVE

5

6

Scaffold no.:
13

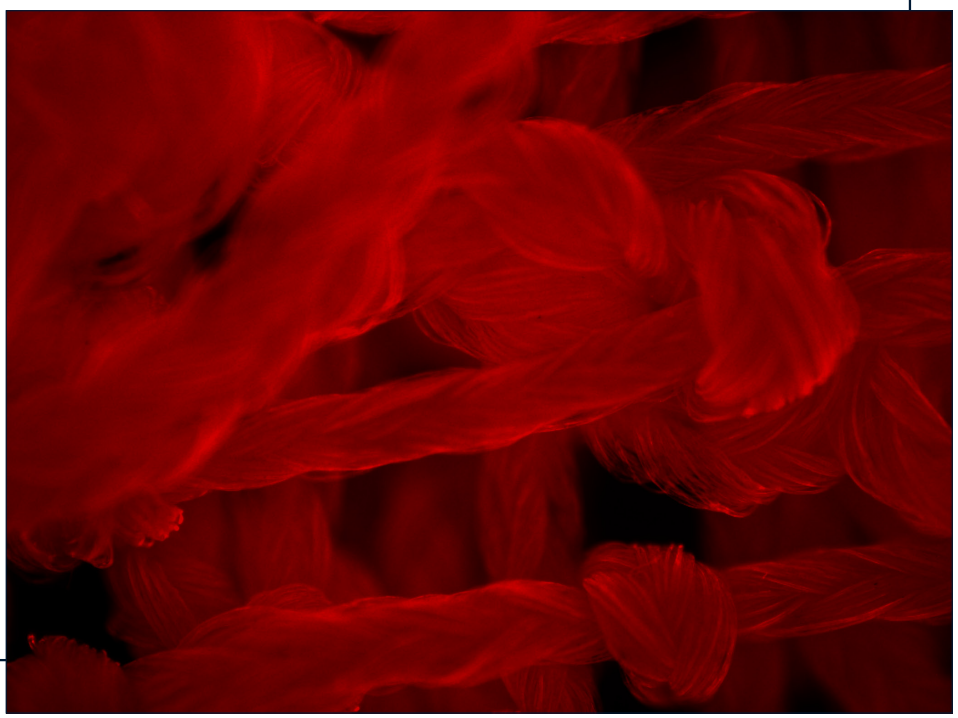
Microseed:
100 µL

Cell type:
HGF1

Passage no.:
P16

Magnification:
x40

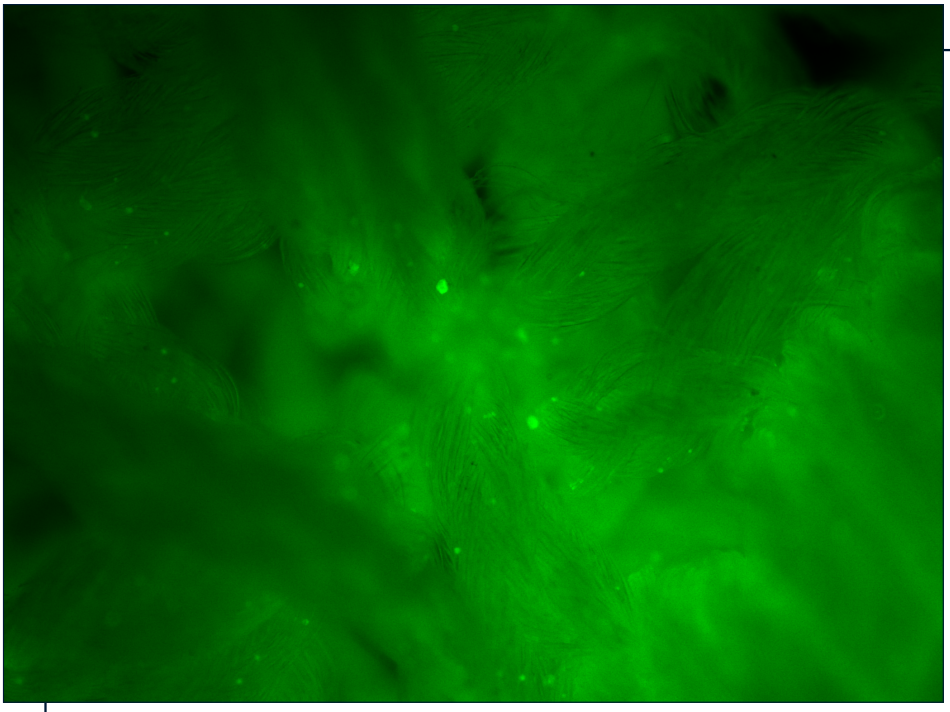
DEAD
(same image as above)



CONSTRUCTED EXPERIMENT 2

4 day
LIVE DEAD

RESULTS



Scaffold no.:
13

Microseed:
50 µL

Cell type:
HGF1

Passage no.:
P16

Magnification:
x40

LIVE

1

2

Scaffold no.:
13

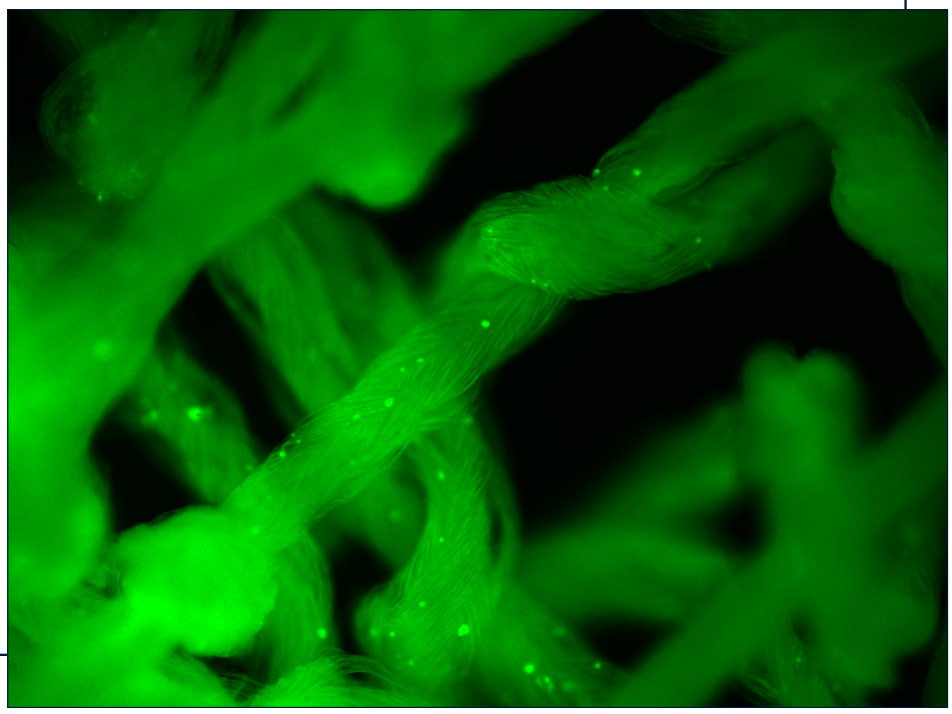
Microseed:
100 µL

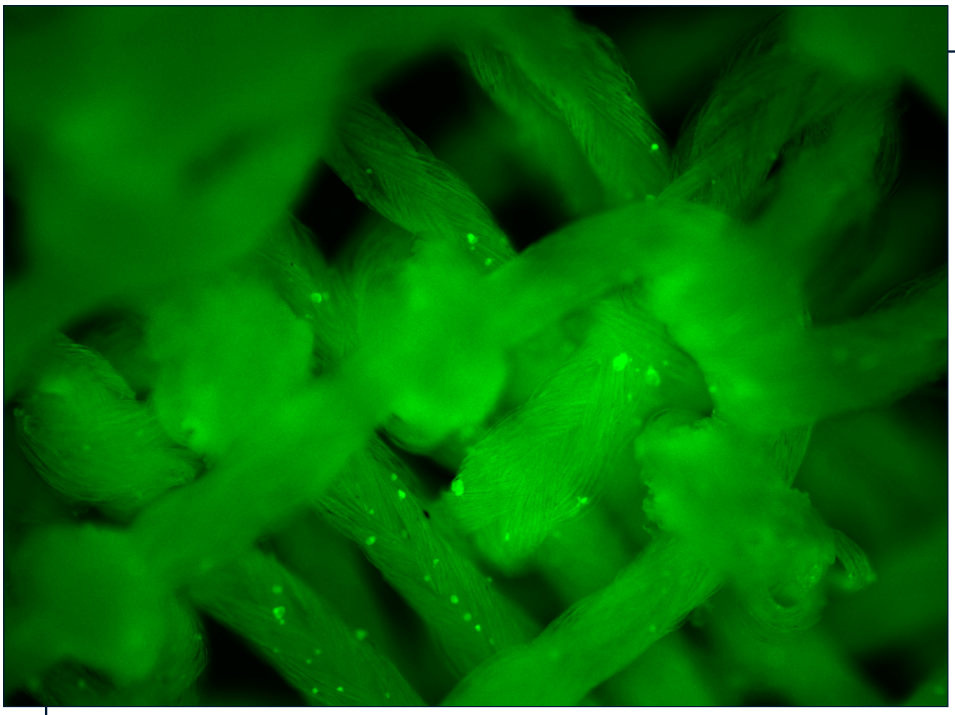
Cell type:
HGF1

Passage no.:
P16

Magnification:
x100

LIVE





Scaffold no.:
13

Microseed:
100 µL

Cell type:
HGF1

Passage no.:
P16

Magnification:
x40

LIVE

3

4

Scaffold no.:
13

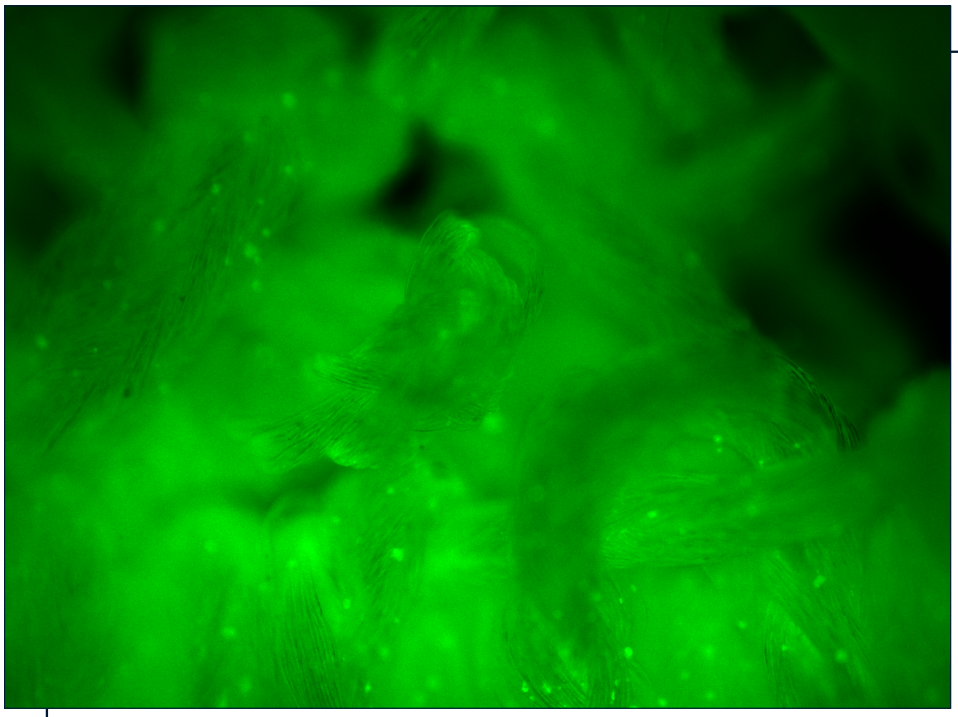
Microseed:
100 µL

Cell type:
HGF1

Passage no.:
P16

Magnification:
x40

DEAD
(same image as above)



Scaffold no.:
13

Microseed:
100 µL

Cell type:
HGF1

Passage no.:
P16

Magnification:
x40

LIVE

5

6

Scaffold no.:
13

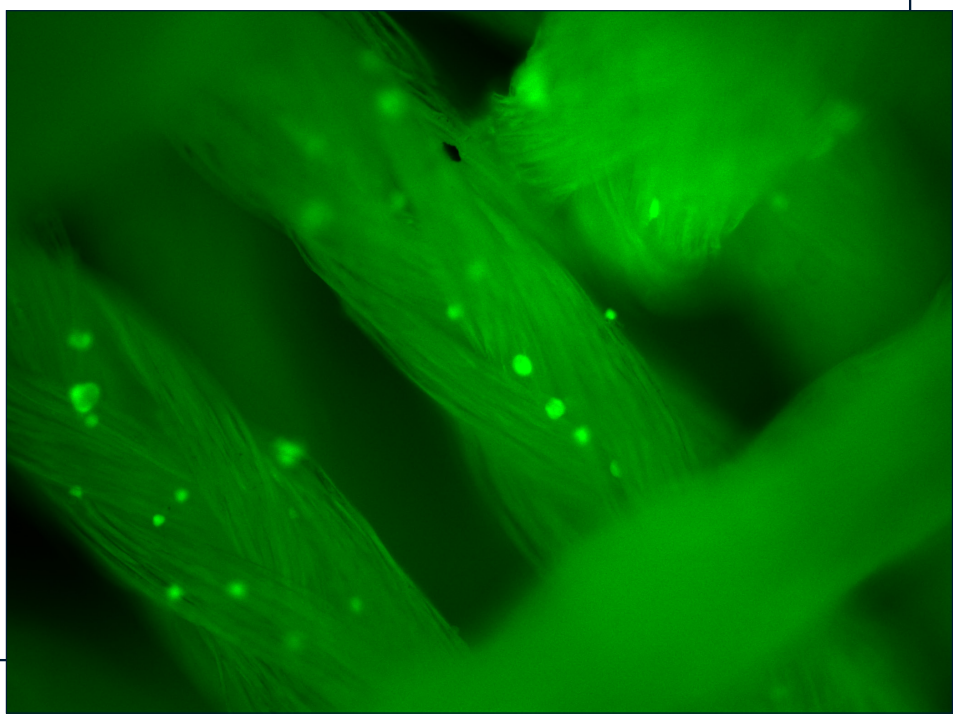
Microseed:
100 µL

Cell type:
HGF1

Passage no.:
P16

Magnification:
x100

LIVE



RESULTS

FINDINGS

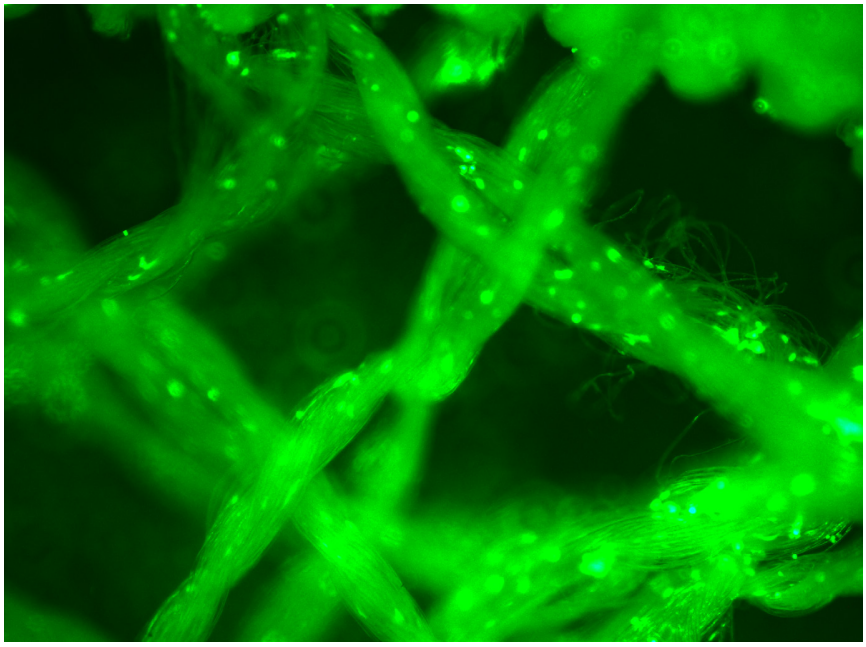
1. Seeding at 100 µL was the most successful concentration.
2. The cells attached to the scaffold well and there were very few, if any, dead cells showing on all of the scaffolds
3. By day 4 the cells had proliferated, especially those seeded at 100 µL concentration.
4. The cells began to show signs of orientating themselves around the scaffolds
5. The cells had not fully elongated into a classic fibroblast shape - this could be due to the silicone coating on the silk suture thread

NEXT STEPS

- Create scaffolds using plain silk thread to see if the cells elogate and attach better without the silicone coating
- Use HOB GFP+ cells so that I can image live cultures and leave the scaffolds in media for a longer period to track how much they continue to orientate themselves and proliferate
- Try different stitch types now I know the best way to set up the experiment and seed my scaffolds
- Longer term - think about designing my own culture dishes and weighting systems to allow greater flexibility in designing experiments.

CONSTRUCTED EXPERIMENT 3

24 hr

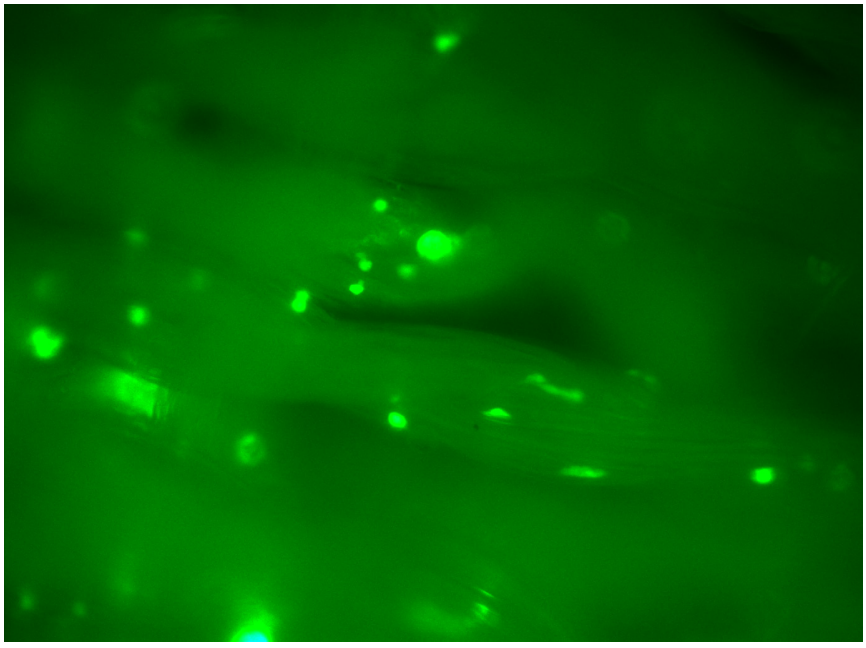


Scaffold no:
3

Cell type:
HOB

Material:
Silk (plain)

Magnification:
x40

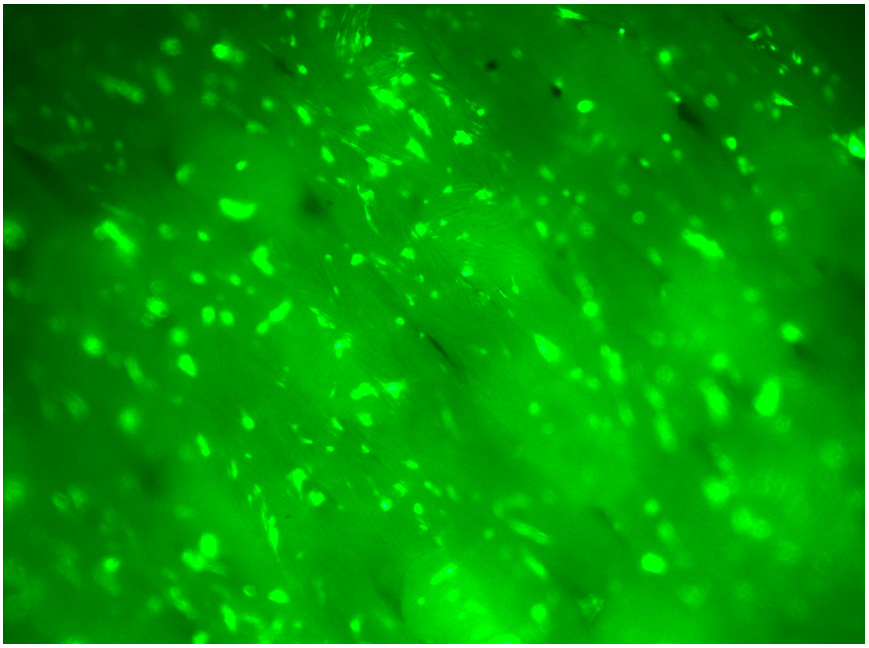


Scaffold no:
2

Cell type:
HOB

Material:
Silk (plain)

Magnification:
x100

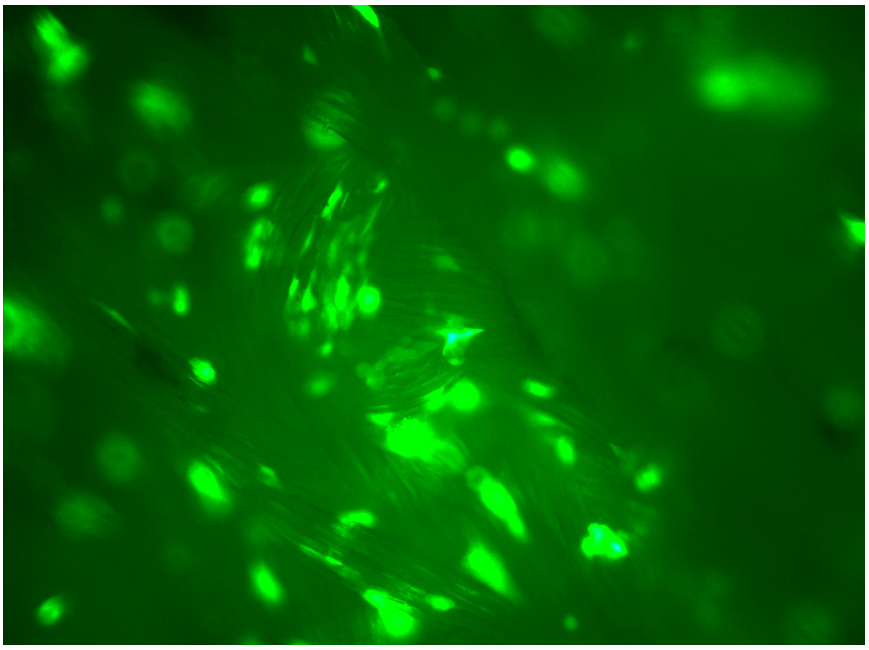


Scaffold no:
2

Cell type:
HOB

Material:
Suture (silk)

Magnification:
x40

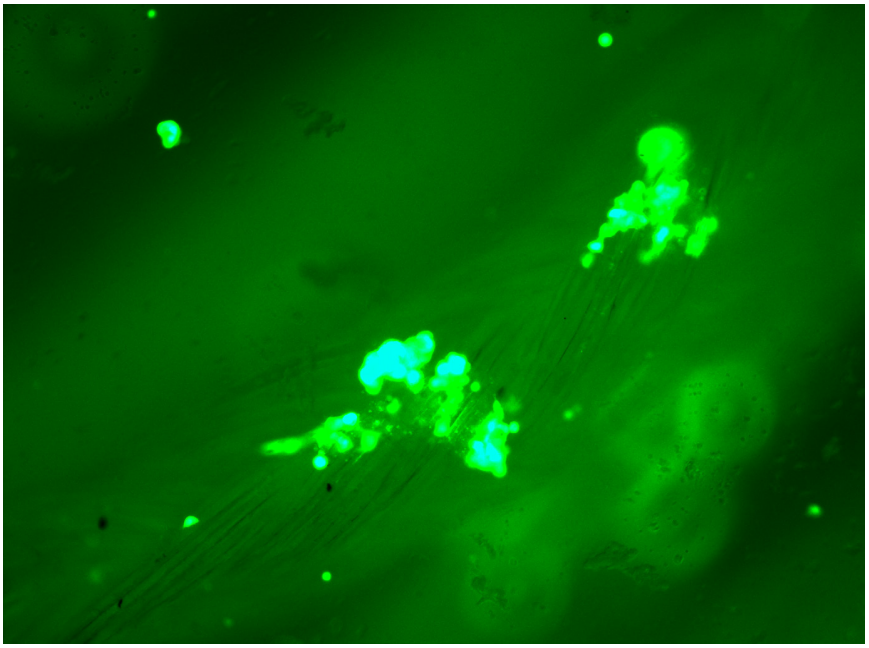


Scaffold no:
2

Cell type:
HOB

Material:
Suture (silk)

Magnification:
x100



Scaffold no:
1

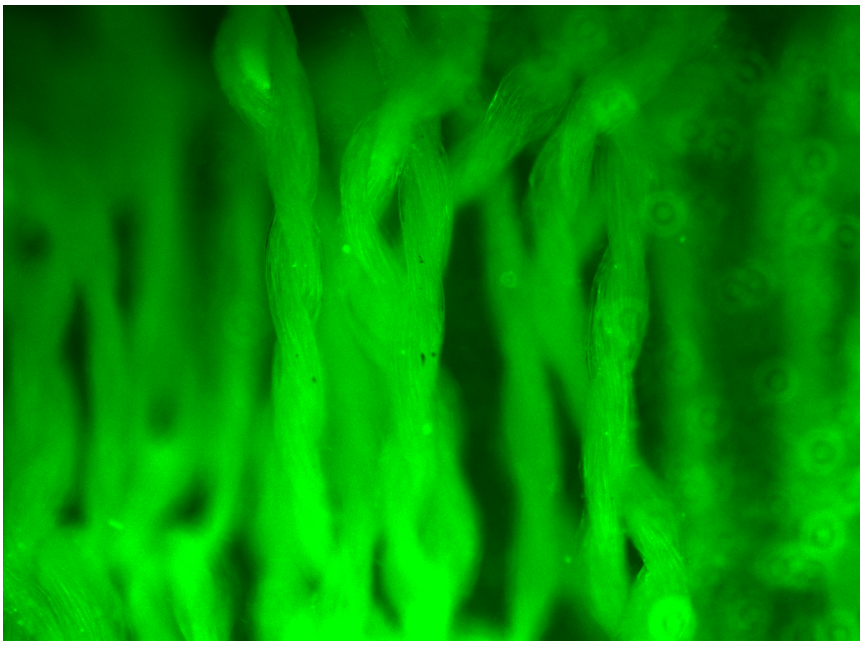
Cell type:
HOB

Material:
Suture (silk)

Magnification:
x100

CONSTRUCTED EXPERIMENT 3

3.5 DAYS

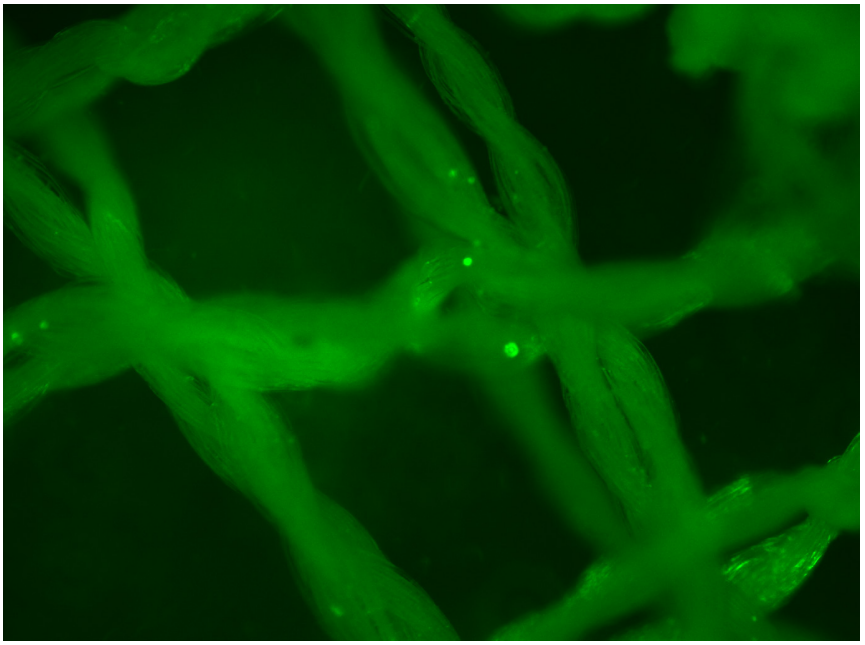


Scaffold no:
1

Cell type:
HOB

Material:
Silk (plain)

Magnification:
x40

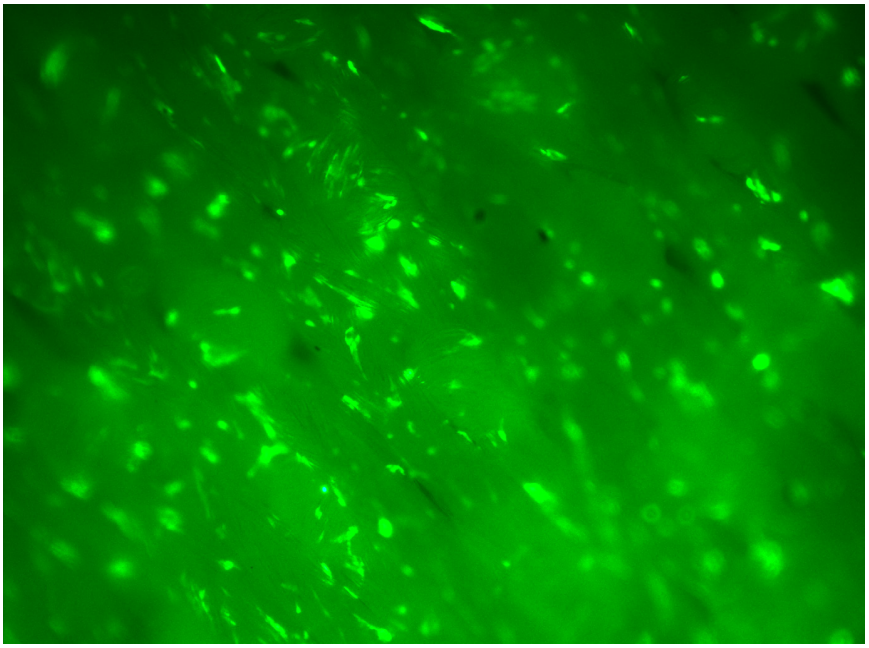


Scaffold no:
3

Cell type:
HOB

Material:
Silk (plain)

Magnification:
x40

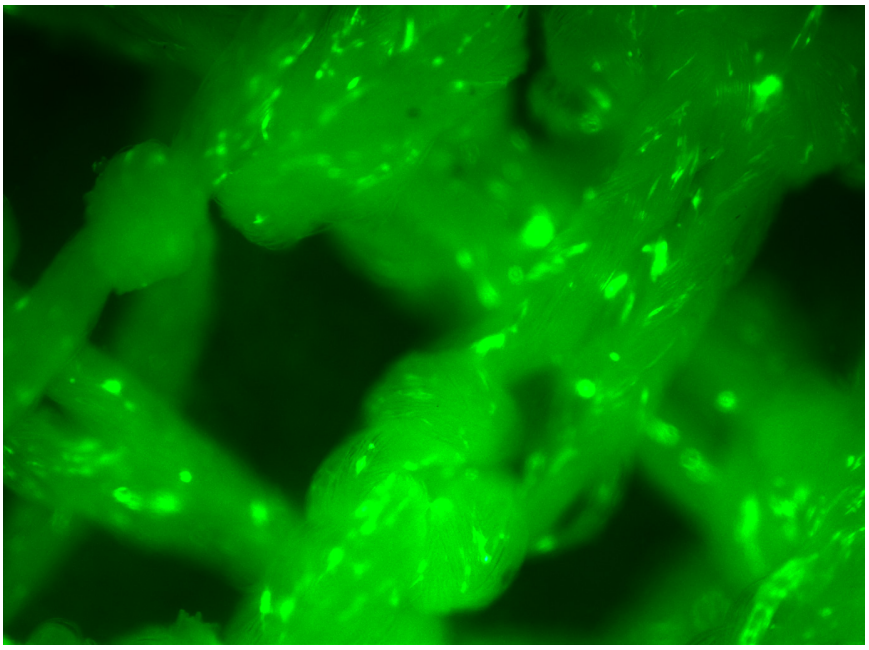


Scaffold no:
2

Cell type:
HOB

Material:
Suture (silk)

Magnification:
x40

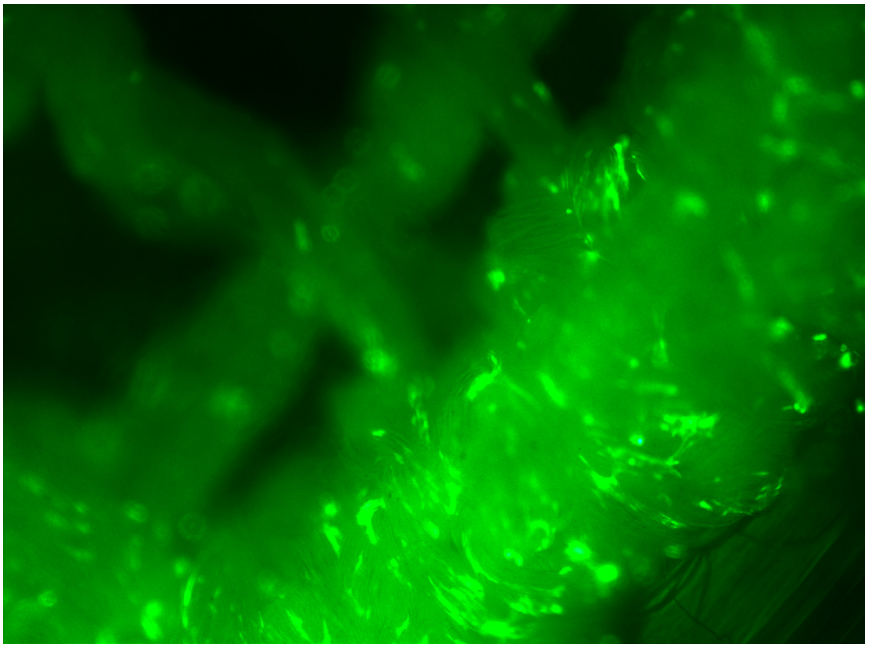


Scaffold no:
3

Cell type:
HOB

Material:
Suture (silk)

Magnification:
x40



Scaffold no:
3

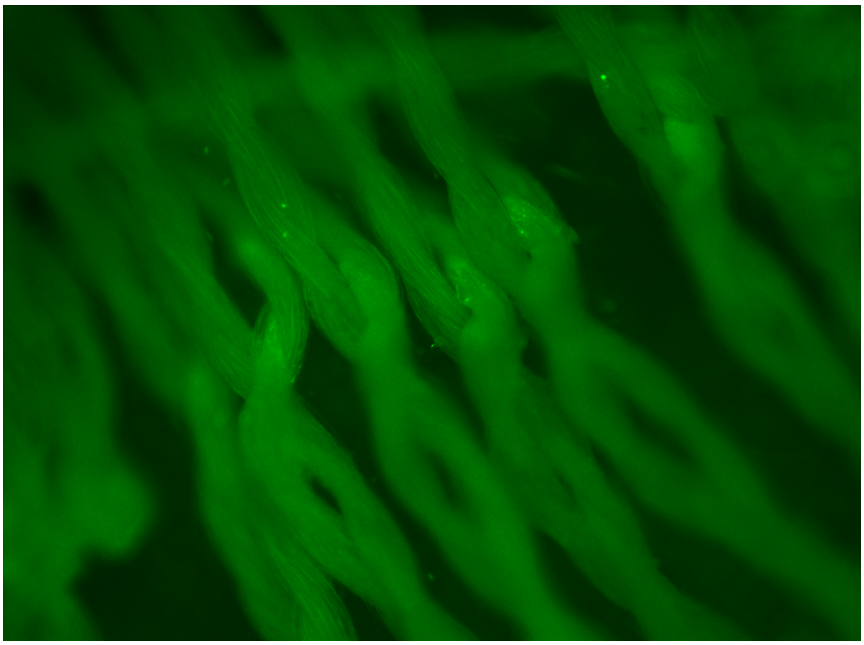
Cell type:
HOB

Material:
Suture (silk)

Magnification:
x40

CONSTRUCTED EXPERIMENT 3

8 DAYS

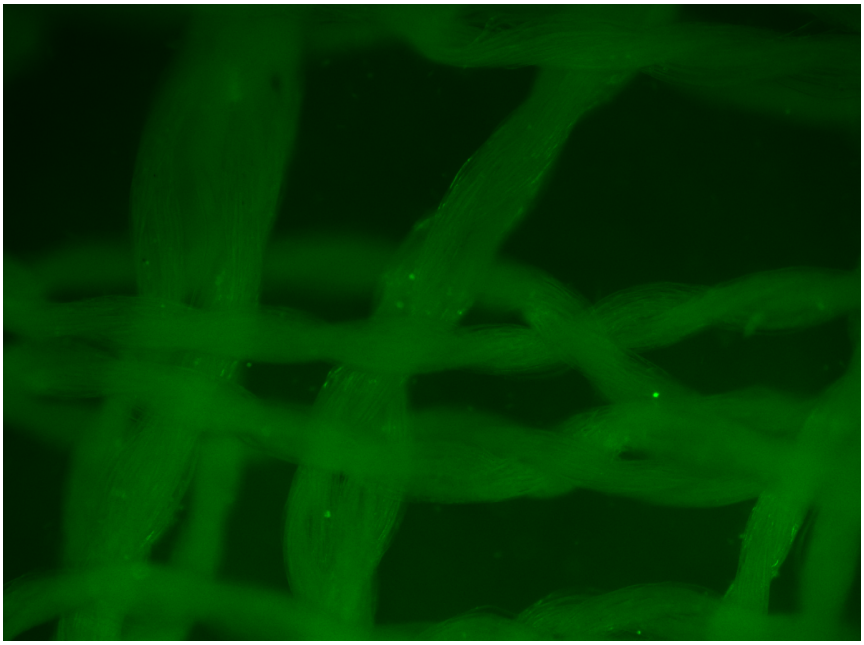


Scaffold no:
1

Cell type:
HOB

Material:
Silk (plain)

Magnification:
x40

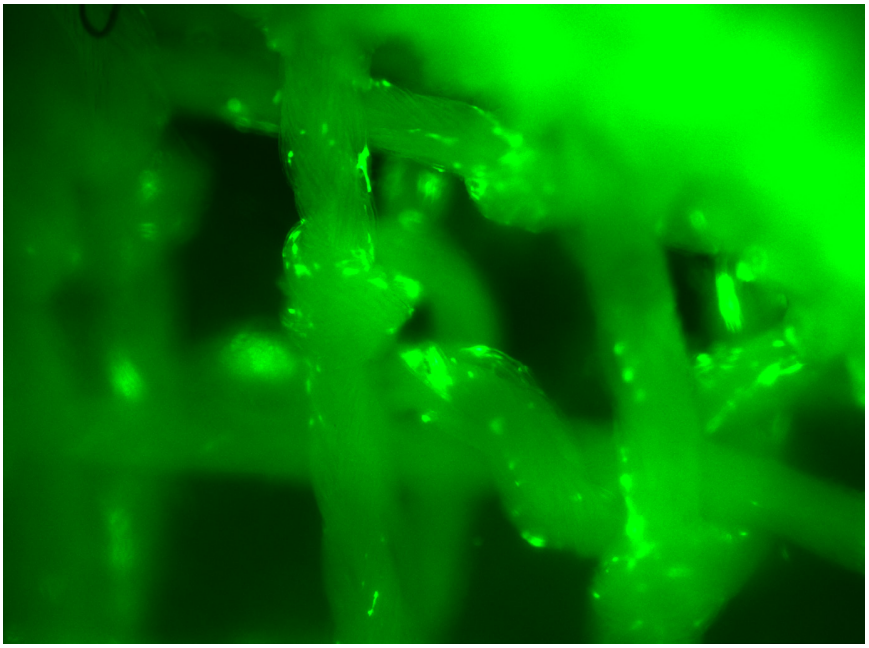


Scaffold no:
3

Cell type:
HOB

Material:
Silk (plain)

Magnification:
x40

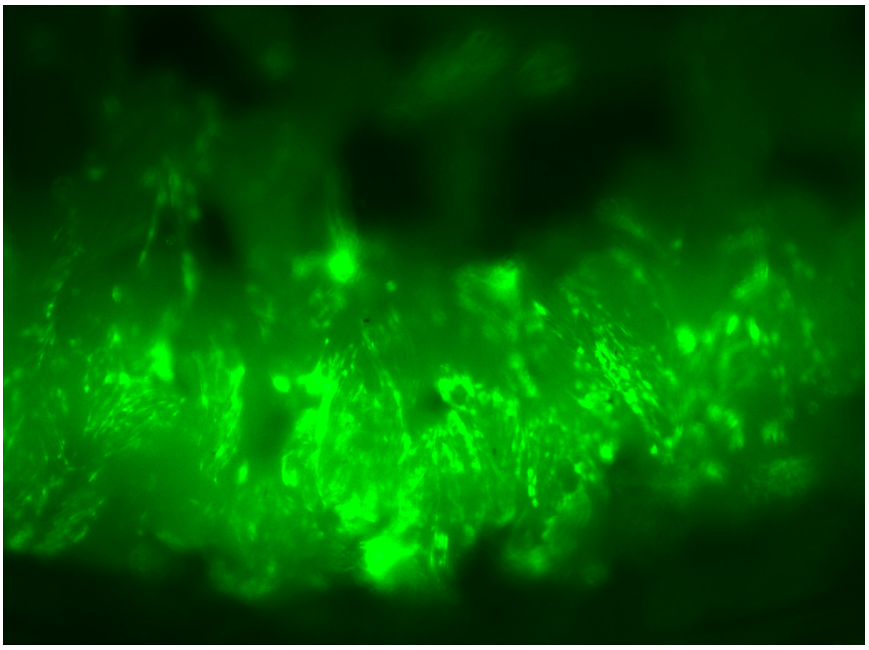


Scaffold no:
3

Cell type:
HOB

Material:
Suture (silk)

Magnification:
x40

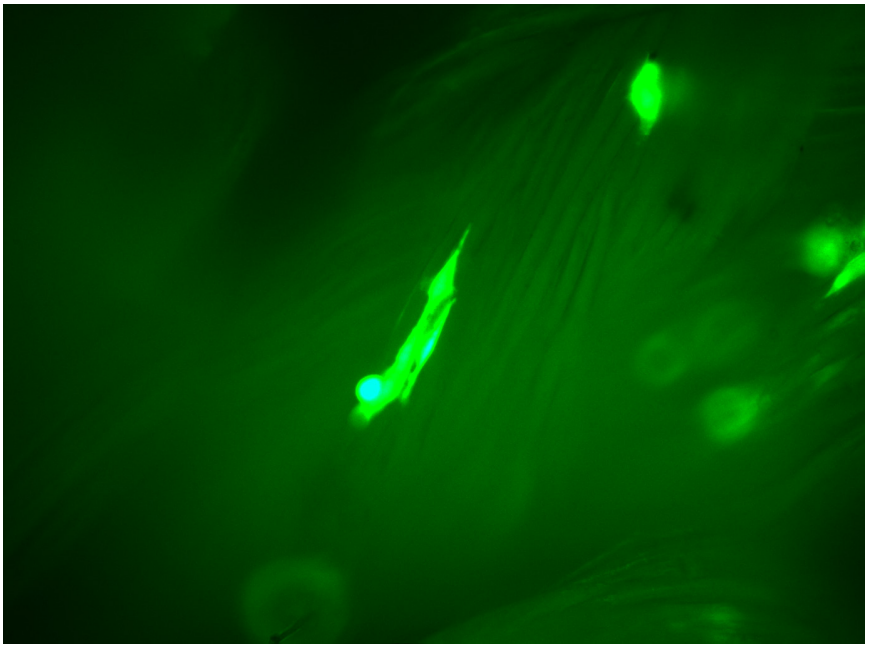


Scaffold no:
3

Cell type:
HOB

Material:
Suture (silk)

Magnification:
x40



Scaffold no:
1

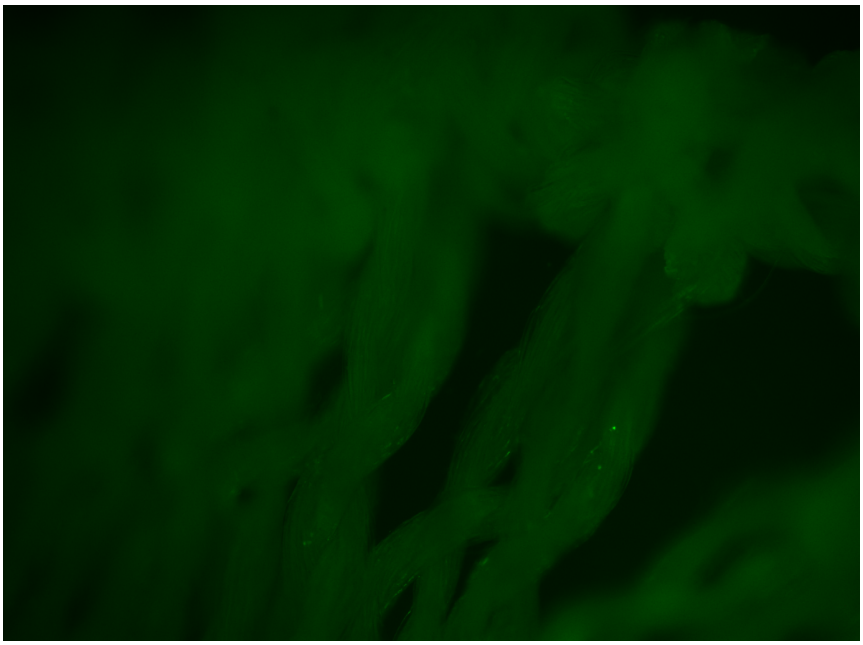
Cell type:
HOB

Material:
Suture (silk)

Magnification:
x200

CONSTRUCTED EXPERIMENT 3

11 DAYS

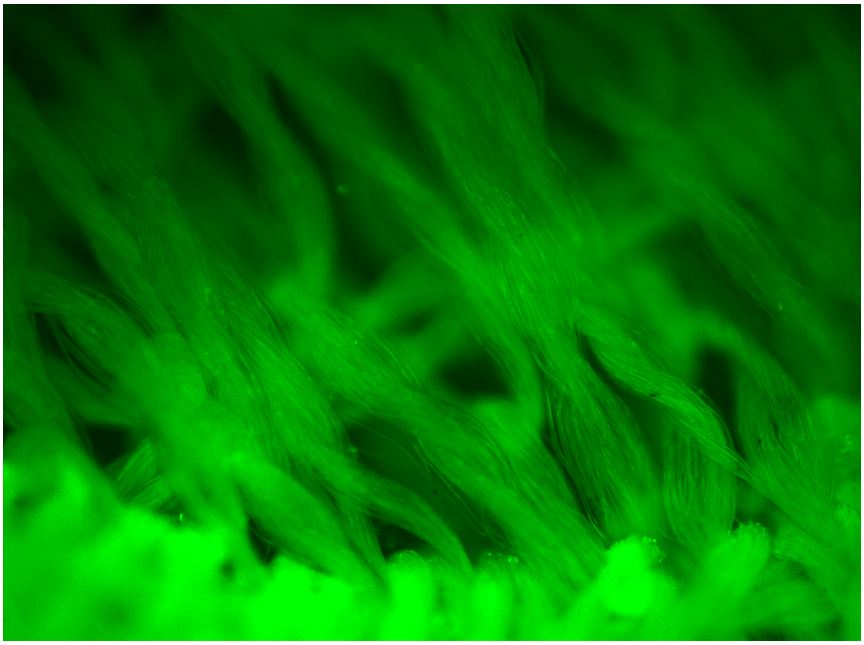


Scaffold no:
1

Cell type:
HOB

Material:
Silk (plain)

Magnification:
x40

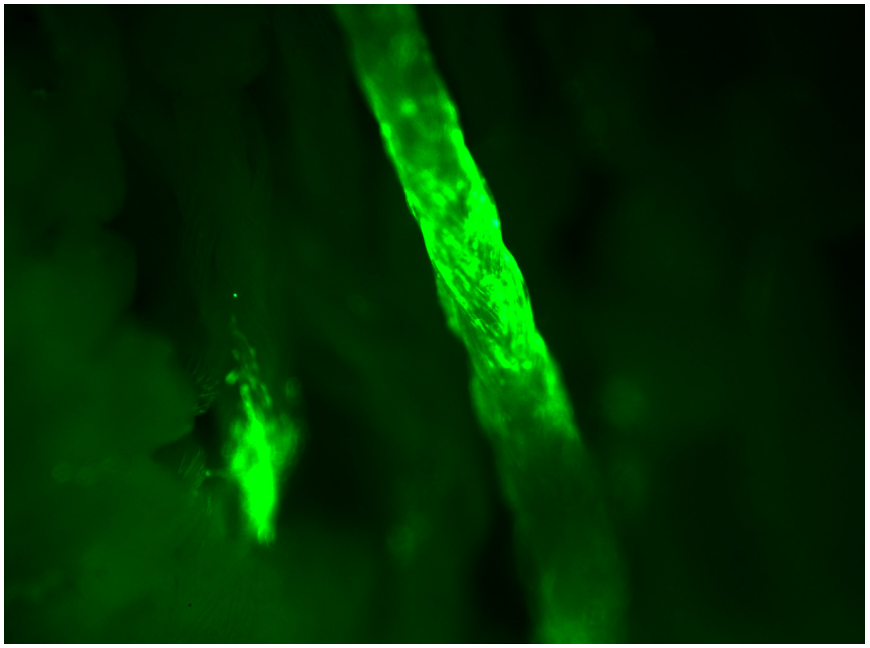


Scaffold no:
2

Cell type:
HOB

Material:
Silk (plain)

Magnification:
x40

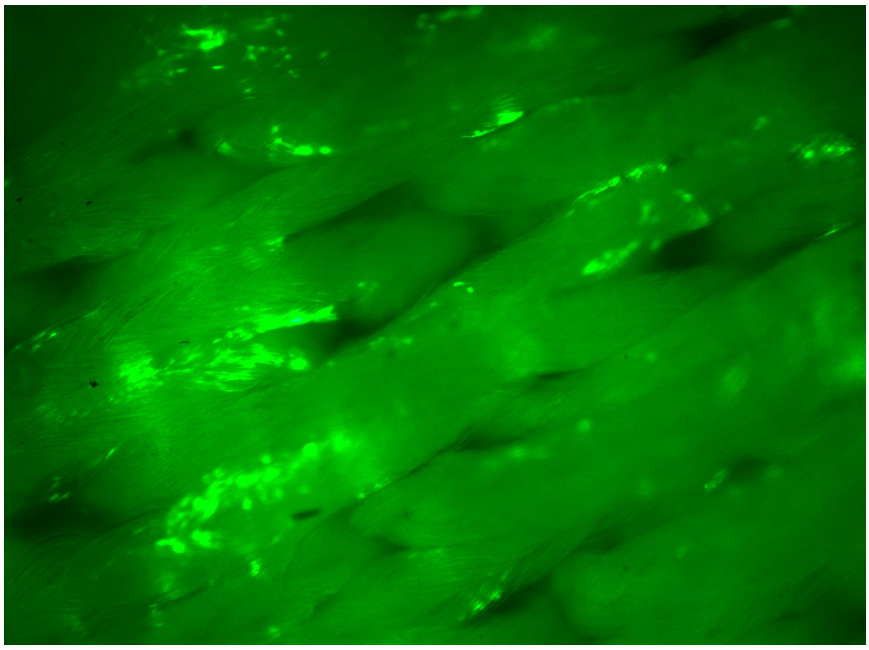


Scaffold no:
1

Cell type:
HOB

Material:
Suture (silk)

Magnification:
x40

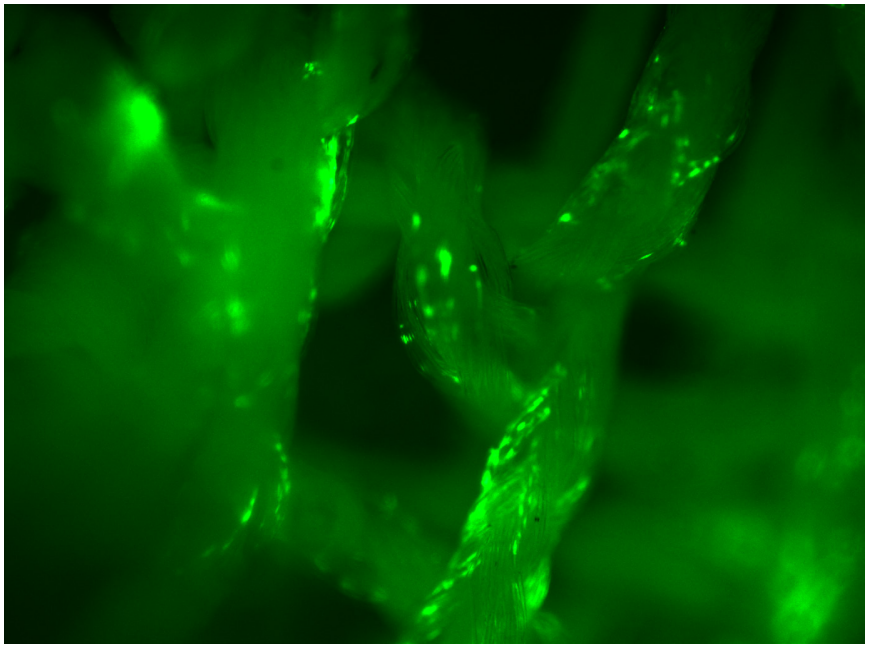


Scaffold no:
2

Cell type:
HOB

Material:
Suture (silk)

Magnification:
x40



Scaffold no:
3

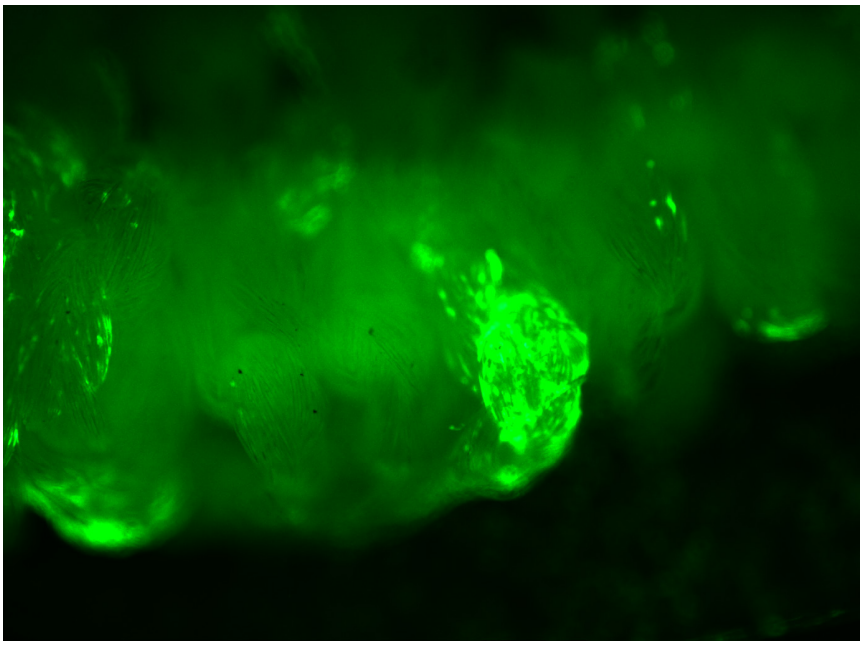
Cell type:
HOB

Material:
Suture (silk)

Magnification:
x40

CONSTRUCTED EXPERIMENT 3

15 DAYS

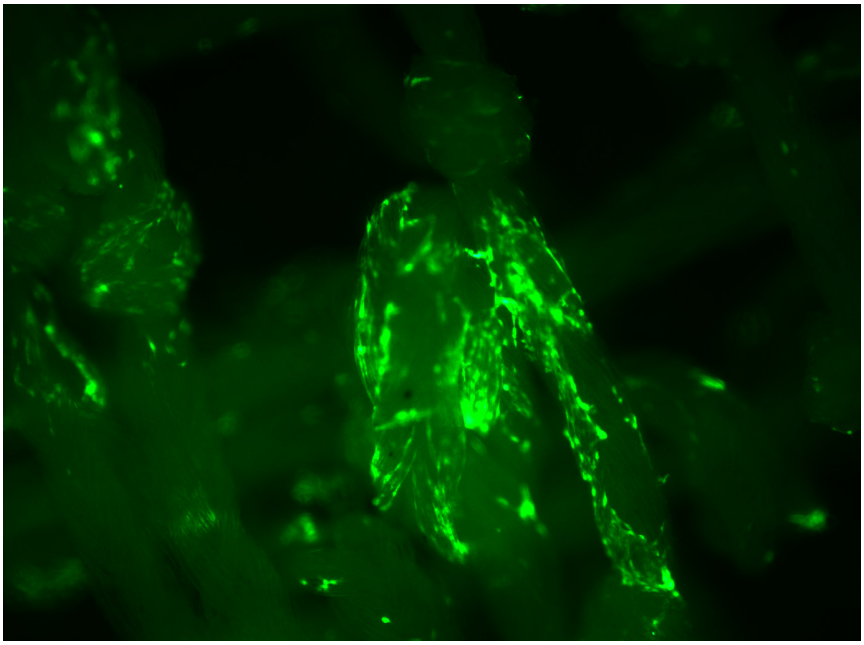


Scaffold no:
1

Cell type:
HOB

Material:
Suture (silk)

Magnification:
x40

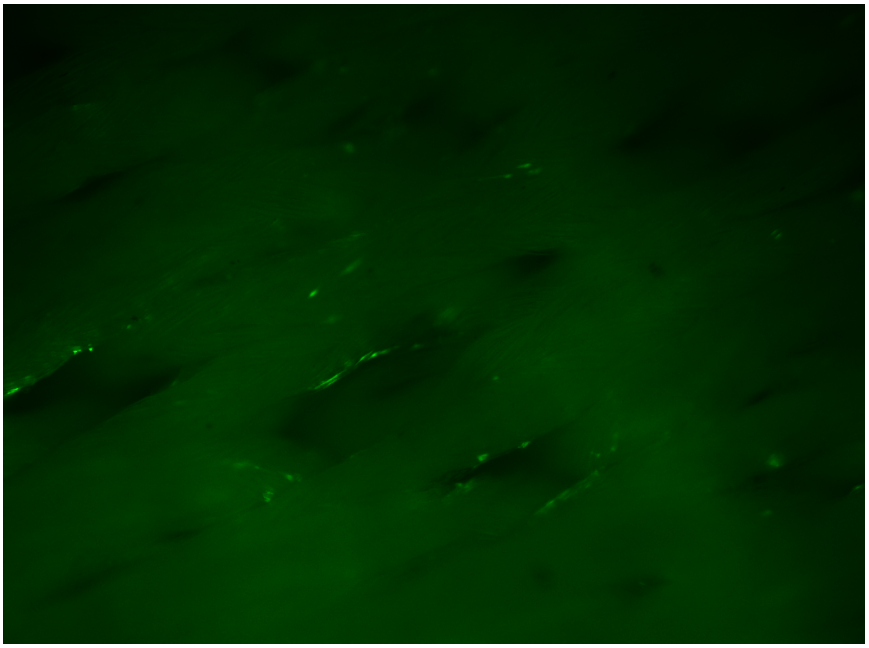


Scaffold no:
3

Cell type:
HOB

Material:
Suture (silk)

Magnification:
x40

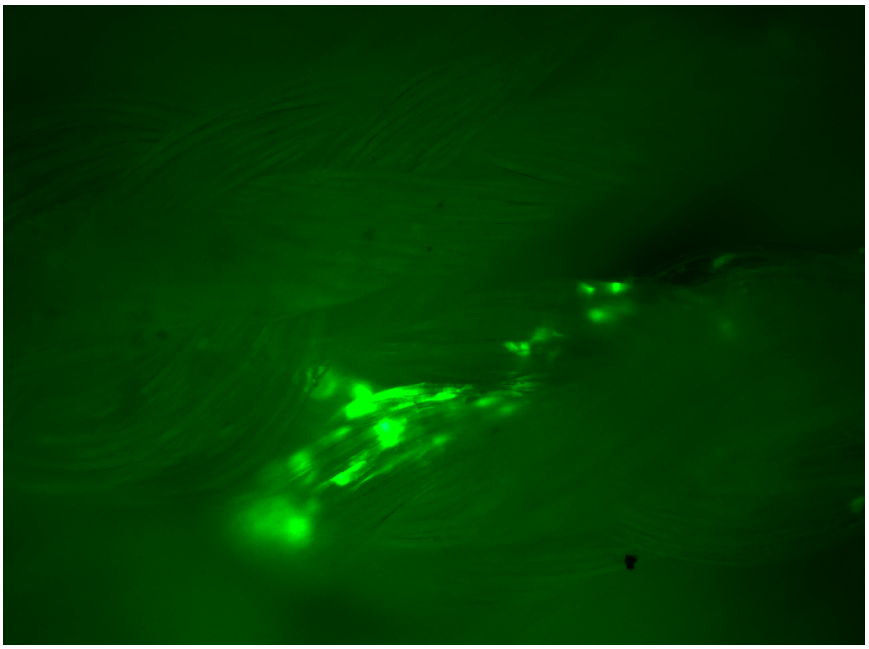


Scaffold no:
2

Cell type:
HOB

Material:
Suture (silk)

Magnification:
x40

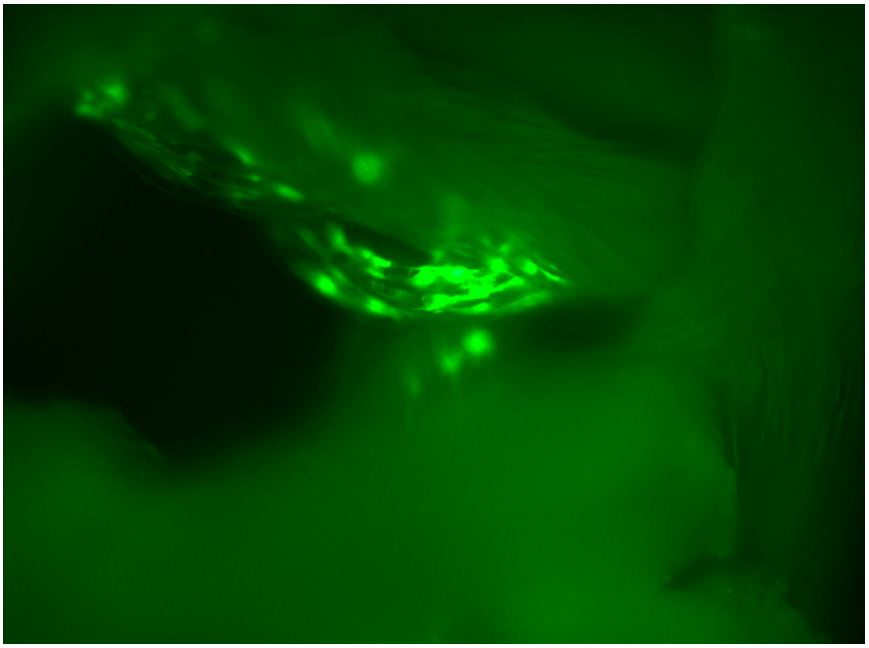


Scaffold no:
2

Cell type:
HOB

Material:
Suture (silk)

Magnification:
x100



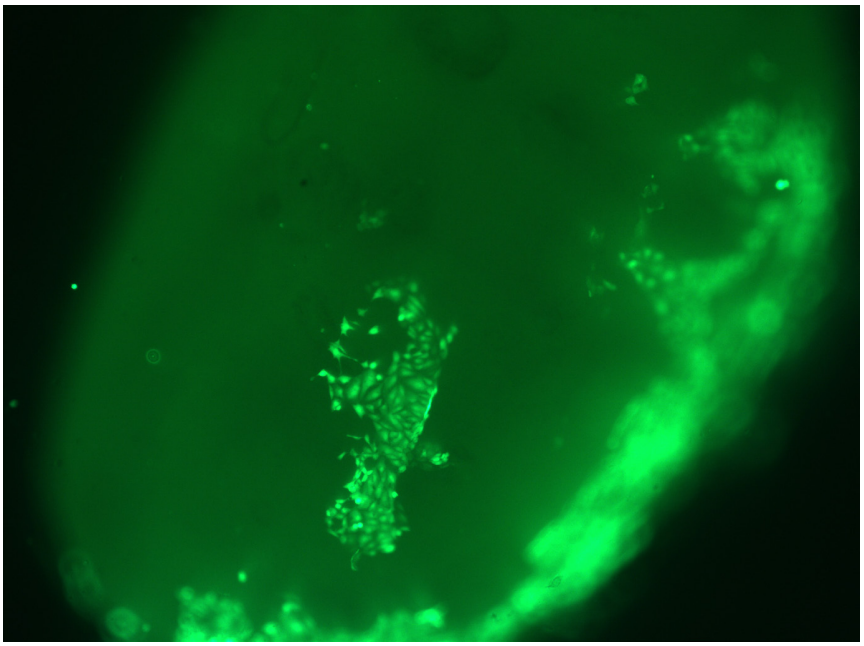
Scaffold no:
3

Cell type:
HOB

Material:
Suture (silk)

Magnification:
x100

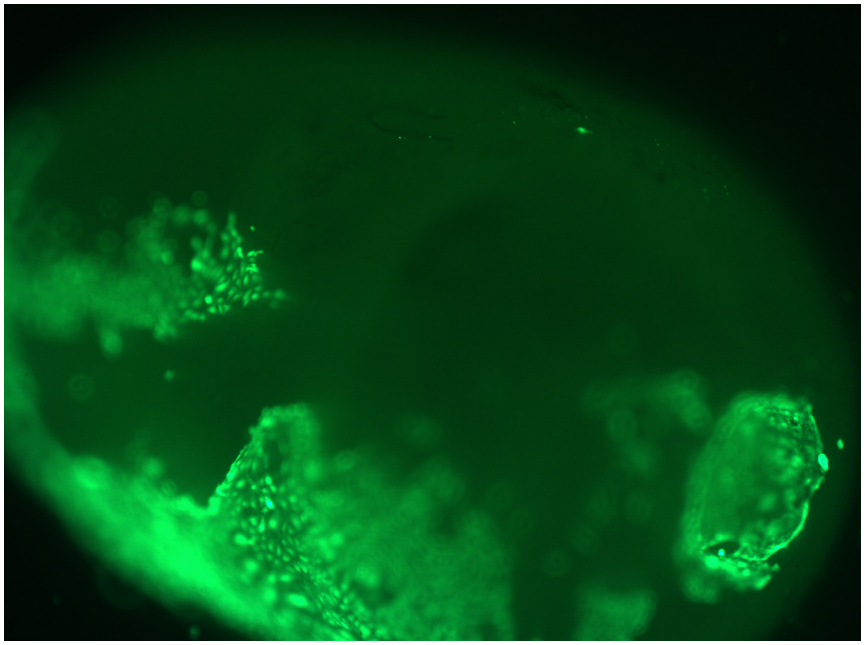
BIOFABRICATE EXPERIMENT



Material:
Freshwater Pearl

Cell type:
HOS

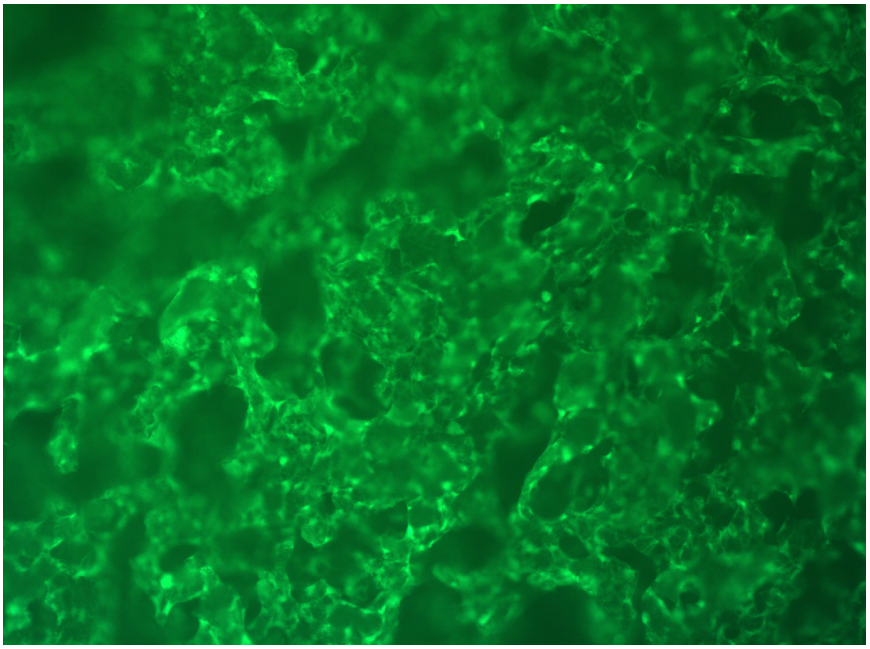
Magnification:
x4



Material:
Freshwater Pearl

Cell type:
HOS

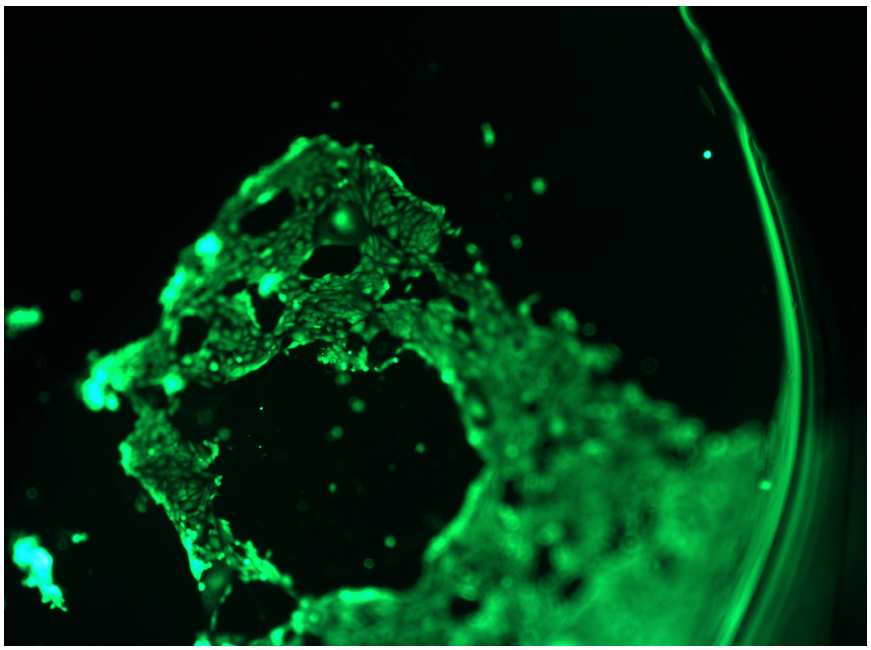
Magnification:
x10



Material:
Calcium Phosphate

Cell type:
HOS

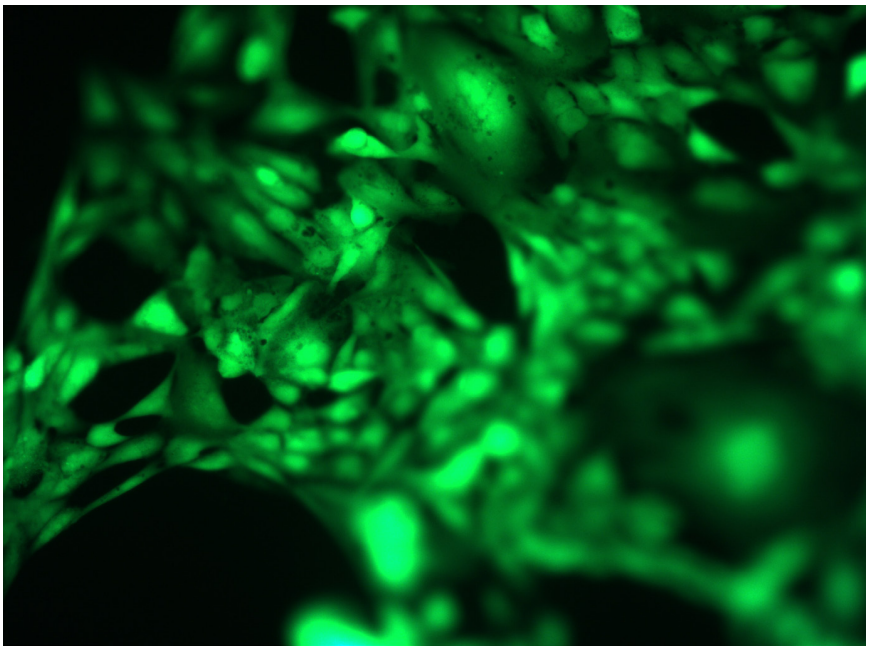
Magnification:
x10



Material:
Swarovski

Cell type:
HOS

Magnification:
x4



Material:
Swarovski

Cell type:
HOS

Magnification:
x20

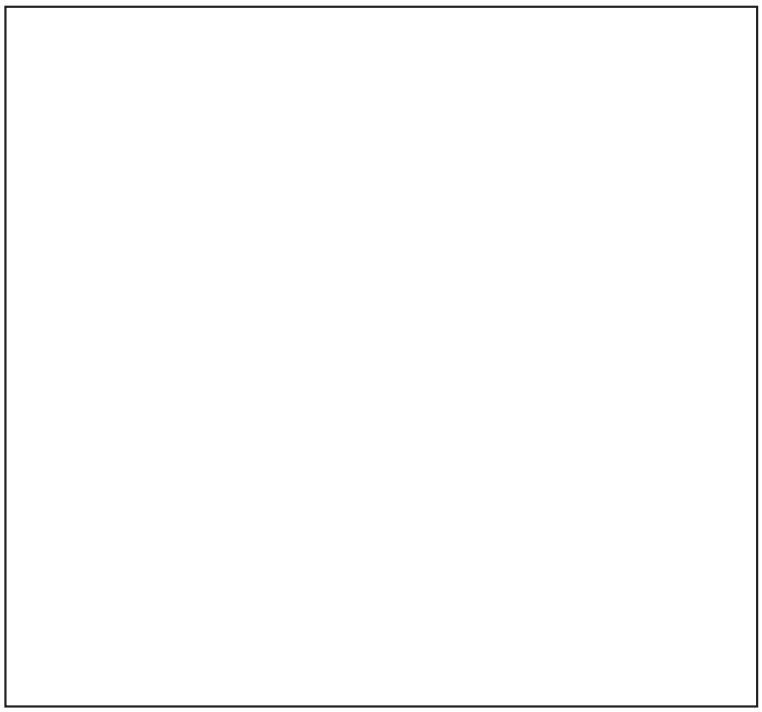
APPENDIX 3

MATERIAL ARCHIVE

Cotton

Cotton

MATERIAL SAMPLE



MATERIAL SIZE

170 microns (0.17mm)

MATERIAL STRUCTURE

High S Twist 60/1nm

NOTES

- Fabric source: http://www.handweavers.co.uk/cgi-bin/sh000001.pl?WD=high%20twist%20cotton&PN=white60_1HTC_120_Z%2ehtml#SID=116
- Fibre was 'wetable', but did twist in on itself in liquid
- Autofluorescence - does not appear to auto-fluoresce green, but does slightly in red

Experiment 1

DATE	25.01.2016
CELL TYPE	HUVECs *(Human umbilical vein endothelial cells)*
MEDIA TYPE	Endothelial Growth Media 2 (EGM2) *Made by Promocell*
MATERIALS SEEDED	Cotton, Horsehair, Milk, Mohair, Nylon Monofilament, Polyester, SeaCell, Silk, Silk/Steel, Soya

AIM

To assess cell adherence, viability and orientation on a range of 10 different yarns

---

PROTOCOL

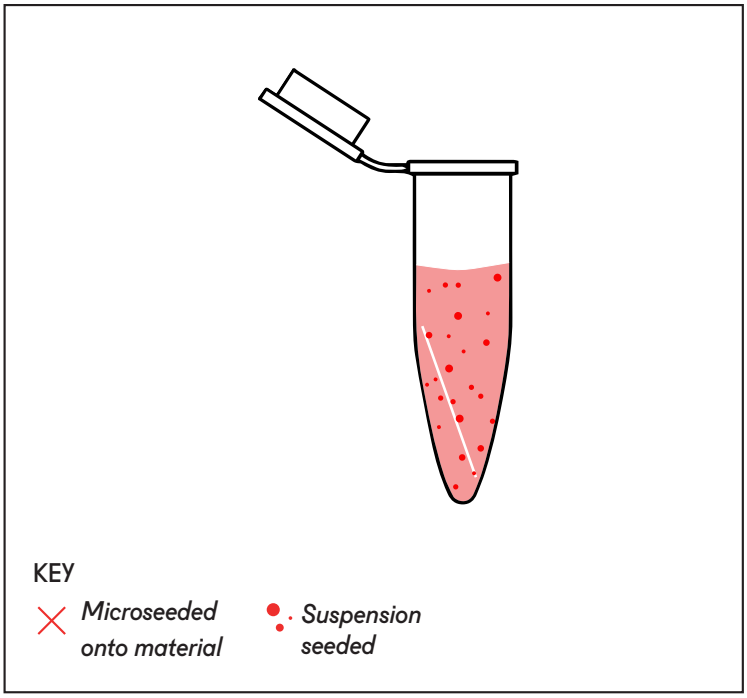
SEEDING

- Grow sufficient number of HUVEC cells to be able to seed all materials - for this experiment each material needs 50,000 cells
- Using sterile tweezers transfer autoclaved material samples into separate eppendorf tubes
- Trypsinize cells, count (re-suspended in 5ml media) and make up concentration of 50,000 cells per 100ml (times by the amount needed - in this case 1ml)
- Tag half of the cells (500ml) with Invitrogen C7025 cell tracker and the other half with Invitrogen C34552 cell tracker and then mix so each scaffold has both colour tracked cells
- Pipette 100ml of cell/ media mix into eppendorf with material sample and then add 400ml of media to make up to 500ml in total
- Place closed tubes in shaker at 37 °C, at 600rpm, and leave for 2 hours
- After 2 hours remove materials from eppendorf tubes and place in separate wells of a 24 well plate. Add media from tube to cover sample. Incubate for 24hrs and then fix for imaging

FIXING

- Remove media and add 1ml of PFA to each well, leave for 30 mins
- Remove PFA, add 1ml of PBS to each well, and agitate for 10mins, repeat.
- Place each material sample on a glass slide, add 150ml of moviol and add cover slip, leave to set for 24hrs

SEEDING



NOTES

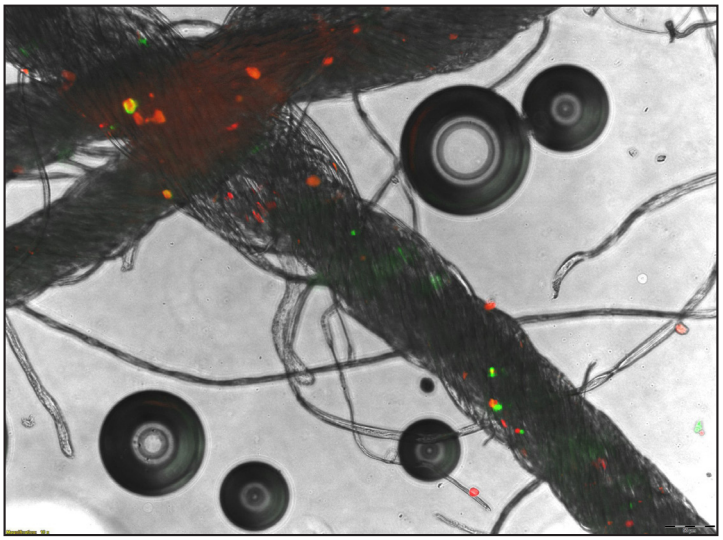
- The different material samples were autoclaved in bags in longer than the required length, they therefore needed cutting down in sterile conditions. This was done by using a sterile petri dish and scalpel blade - cutting approx. 1cm samples of each material and then transferring these to the eppendorf tubes.

- For ease in future experiments it would be better to cut down the material samples to the correct length and autoclave them in a glass petri dish so they are easily found and picked up by tweezers - small samples tend to be lost in autoclave bags and difficult to retrieve

Results

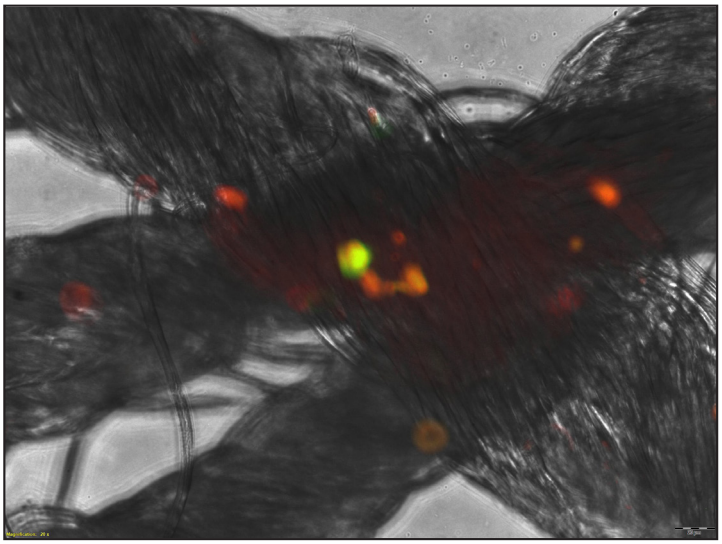
x10 magnification

Brightfield image combined with red & green cell images - composite image 24hrs post seeding



x20 magnification

Brightfield image combined with red & green cell images - composite image 24hrs post seeding



NOTES

- The Cotton was somewhat biologically compatible, there were some cells adhered but they did not look particularly healthy
- During imaging there was crossover in fluorescence between the red and green markers.

Experiment 2

DATE	01.02.2016
CELL TYPE	HUVECs *(Human umbilical vein endothelial cells)*
MEDIA TYPE	Endothelial Growth Media 2 (EGM2) *Made by Promocell*
MATERIALS SEEDED	Cotton, Horsehair, Milk, Mohair, Nylon Monofilament, Polyester, SeaCell, Silk, Silk/Steel, Soya

AIM

To assess cell adherence, viability and orientation on a range of 10 different yarns pre-coated in gelatin

---

PROTOCOL

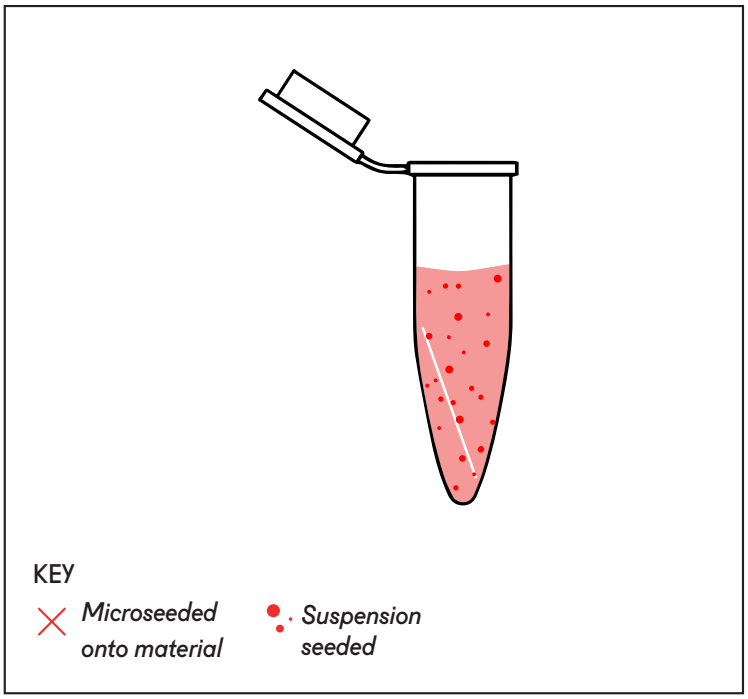
SEEDING

- Grow sufficient number of HUVEC cells to be able to seed all materials - for this experiment each material needs 50,000 cells
- Using sterile tweezers transfer autoclaved material samples into separate eppendorf tubes, the materials were soaked in 0.5% gelatin solution for 24hrs prior to the experiment
- Trypsinize cells, count (re-suspended in 5ml media) and make up concentration of 50,000 cells per 100ml (times by the amount needed - in this case 1ml)
- Tag cells with Invitrogen C34552 cell tracker
- Pipette 100ml of cell/ media mix into eppendorf with material sample and then add 400ml of media to make up to 500ml in total
- Place closed tubes in shaker at 37 °C, at 600rpm, and leave for 2 hours
- After 2 hours remove materials from eppendorf tubes and place in separate wells of a 24 well plate. Add media from tube to cover sample. Incubate for 24hrs and then fix for imaging

FIXING

- Remove media and add 1ml of PFA to each well, leave for 30 mins
- Remove PFA, add 1ml of PBS to each well, and agitate for 10mins, repeat.
- Cells were also Hoechst stained to mark cell nuclei
- Place each material sample on a glass slide, add 150ml of moviol and add cover slip, leave to set for 24hrs

SEEDING



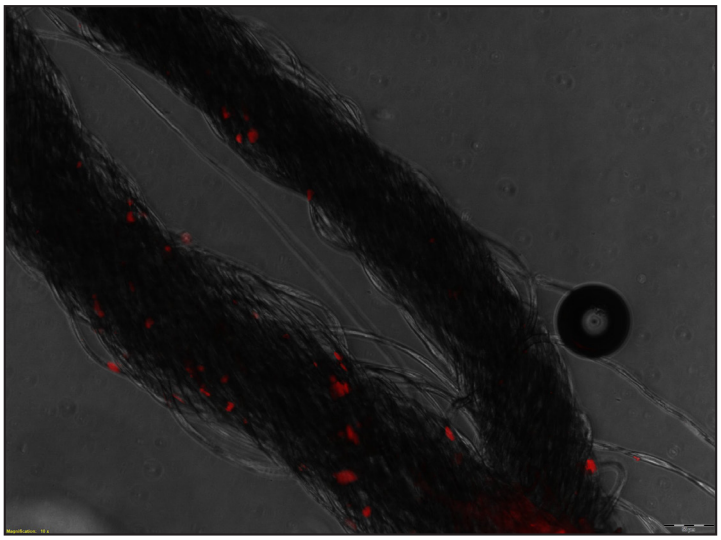
NOTES

- The different material samples were cut to 1cm in length and autoclaved in small glass petri dishes.
- All samples were coated in gelatin prior to seeding to assess if this would improve adherance. The yarns can then be compared to those of experiment 1.
- Only one cell tracker was used, Invitrogen C34552, as it had the least crossover when imaging

Results

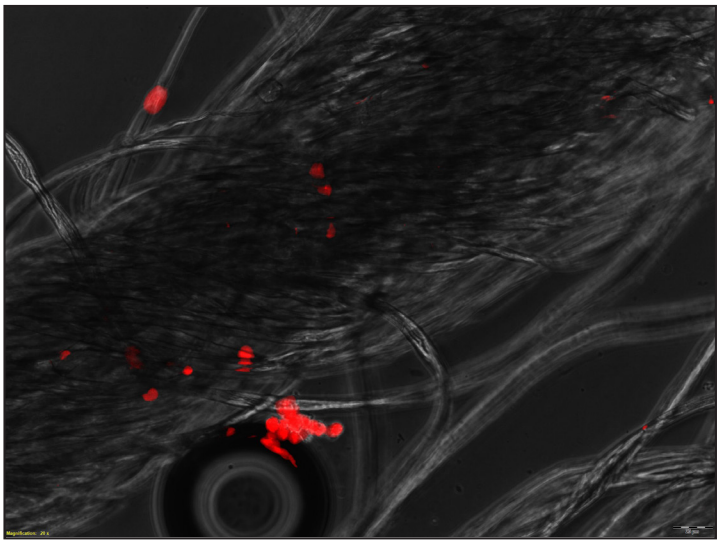
x10 magnification

Brightfield image combined with red cell images - composite image
24hrs post seeding



x20 magnification

Brightfield image combined with red cell images - composite image
24hrs post seeding



NOTES

- There was some indication that the gelatin made the Cotton a little more attractive to the cells, but in both experiment1 and 2 showed simillar number of cells visible under the microscope.
- Imaging the samples post gelatin coating and just after seeding showed a number of cells adhered, however they did not appear to have proliferated during the 24 hrs in culture

Horsehair

Horsehair

MATERIAL SAMPLE

MATERIAL SIZE

150 microns (0.15mm)

MATERIAL STRUCTURE

Single strand of hair

NOTES

- Fabric source:
  http://www.handweavers.co.uk/cgi-bin/sh000001pl?WD=horsehair&PN=horsehair-and-cotton-melange-782%2ehtml#SID=3 (Horsehair separated from cotton casing)
- Fibre was not very 'wetable' i.e. absorbs water quickly and does not float, it will submerge but not ideal
- Autofluorescence - slightly auto-fluoresces in red and green

Experiment 1

DATE	25.01.2016
CELL TYPE	HUVECs *(Human umbilical vein endothelial cells)*
MEDIA TYPE	Endothelial Growth Media 2 (EGM2) *Made by Promocell*
MATERIALS SEEDED	Cotton, Horsehair, Milk, Mohair, Nylon Monofilament, Polyester, SeaCell, Silk, Silk/Steel, Soya

AIM

To assess cell adherence, viability and orientation on a range of 10 different yarns

---

PROTOCOL

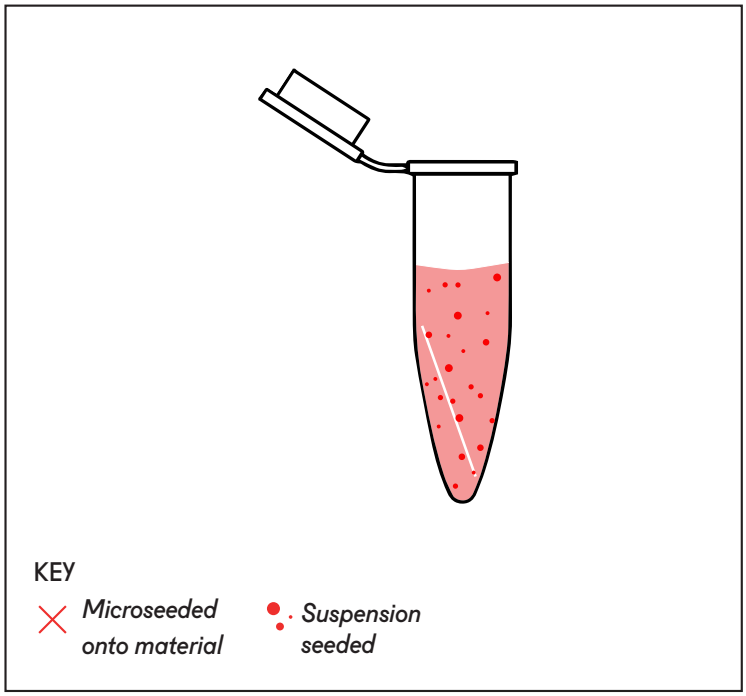
SEEDING

- Grow sufficient number of HUVEC cells to be able to seed all materials - for this experiment each material needs 50,000 cells
- Using sterile tweezers transfer autoclaved material samples into separate eppendorf tubes
- Trypsinize cells, count (re-suspended in 5ml media) and make up concentration of 50,000 cells per 100ml (times by the amount needed - in this case 1ml)
- Tag half of the cells (500ml) with Invitrogen C7025 cell tracker and the other half with Invitrogen C34552 cell tracker and then mix so each scaffold has both colour tracked cells
- Pipette 100ml of cell/ media mix into eppendorf with material sample and then add 400ml of media to make up to 500ml in total
- Place closed tubes in shaker at 37 °C, at 600rpm, and leave for 2 hours
- After 2 hours remove materials from eppendorf tubes and place in separate wells of a 24 well plate. Add media from tube to cover sample. Incubate for 24hrs and then fix for imaging

FIXING

- Remove media and add 1ml of PFA to each well, leave for 30 mins
- Remove PFA, add 1ml of PBS to each well, and agitate for 10mins, repeat.
- Place each material sample on a glass slide, add 150ml of moviol and add cover slip, leave to set for 24hrs

SEEDING



NOTES

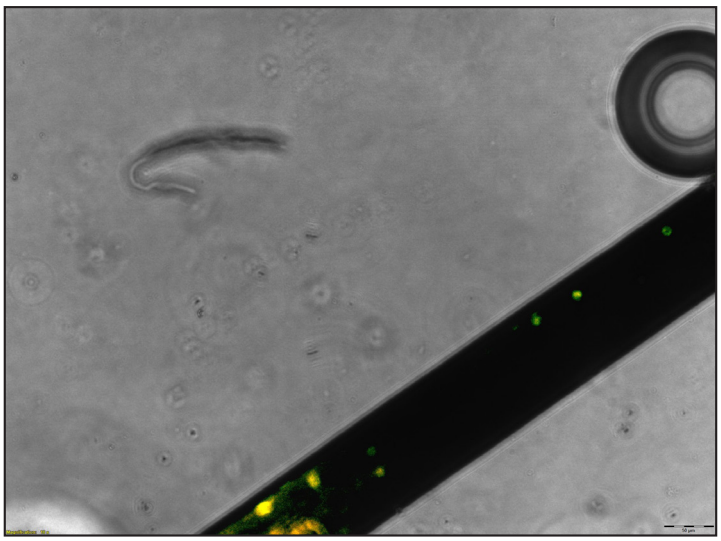
- The different material samples were autoclaved in bags in longer than the required length, they therefore needed cutting down in sterile conditions. This was done by using a sterile petri dish and scalpel blade - cutting approx. 1cm samples of each material and then transferring these to the eppendorf tubes.

- For ease in future experiments it would be better to cut down the material samples to the correct length and autoclave them in a glass petri dish so they are easily found and picked up by tweezers - small samples tend to be lost in autoclave bags and difficult to retrieve

Results

x10 magnification

Brightfield image combined with red & green cell images - composite image 24hrs post seeding



NOTES

- The horsehair had very few cell adhere
- During imaging there was crossover in fluorescence between the red and green markers.

Experiment 2

DATE	01.02.2016
CELL TYPE	HUVECs *(Human umbilical vein endothelial cells)*
MEDIA TYPE	Endothelial Growth Media 2 (EGM2) *Made by Promocell*
MATERIALS SEEDED	Cotton, Horsehair, Milk, Mohair, Nylon Monofilament, Polyester, SeaCell, Silk, Silk/Steel, Soya

AIM

To assess cell adherence, viability and orientation on a range of 10 different yarns pre-coated in gelatin

---

PROTOCOL

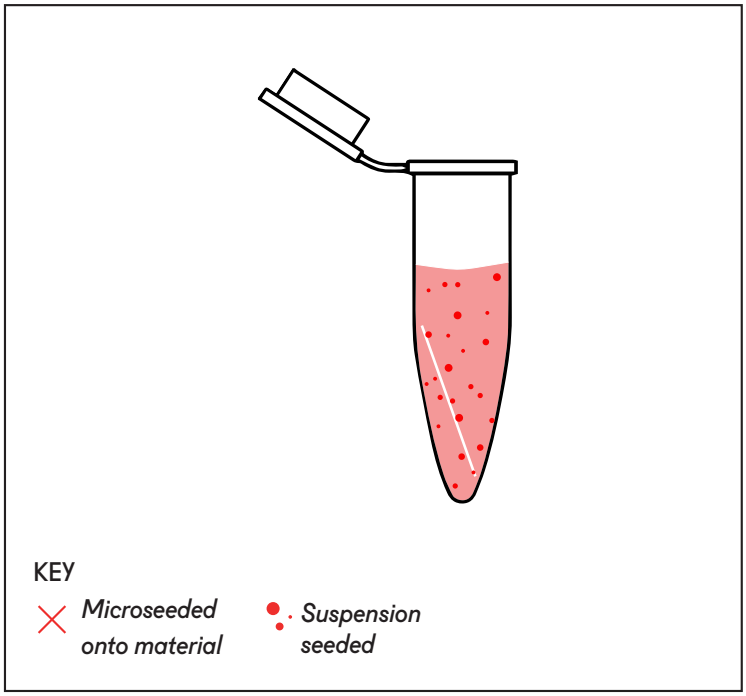
SEEDING

- Grow sufficient number of HUVEC cells to be able to seed all materials - for this experiment each material needs 50,000 cells
- Using sterile tweezers transfer autoclaved material samples into separate eppendorf tubes, the materials were soaked in gelatin for 24hrs prior to the experiment
- Trypsinize cells, count (re-suspended in 5ml media) and make up concentration of 50,000 cells per 100ml (times by the amount needed - in this case 1ml)
- Tag cells with Invitrogen C34552 cell tracker
- Pipette 100ml of cell/ media mix into eppendorf with material sample and then add 400ml of media to make up to 500ml in total
- Place closed tubes in shaker at 37 °C, at 600rpm, and leave for 2 hours
- After 2 hours remove materials from eppendorf tubes and place in separate wells of a 24 well plate. Add media from tube to cover sample. Incubate for 24hrs and then fix for imaging

*F*IXING

- Remove media and add 1ml of PFA to each well, leave for 30 mins
- Remove PFA, add 1ml of PBS to each well, and agitate for 10mins, repeat.
- Cells were also Hoechst stained to mark cell nuclei
- Place each material sample on a glass slide, add 150ml of moviol and add cover slip, leave to set for 24hrs

SEEDING



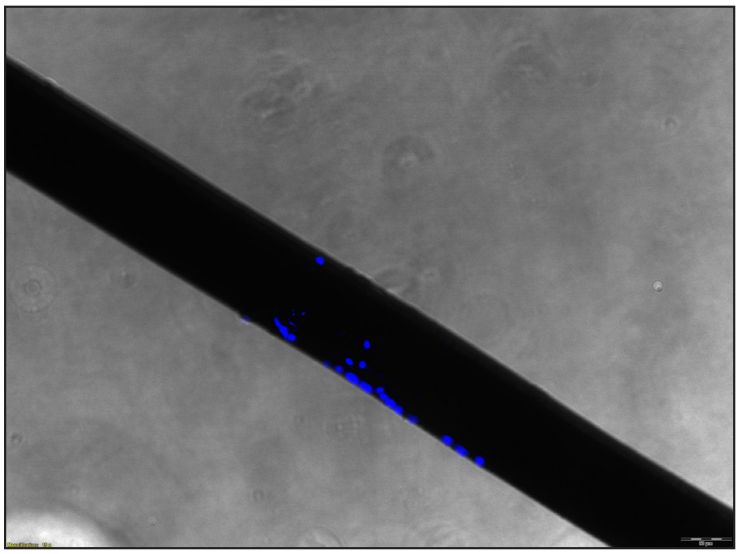
NOTES

- The different material samples were cut to 1cm in length and autoclaved in small glass petri dishes.
- All samples were coated in gelatin prior to seeding to assess if this would improve adherance. The yarns can then be compared to those of experiment 1.
- Only one cell tracker was used, Invitrogen C34552, as it had the least crossover when imaging

Results

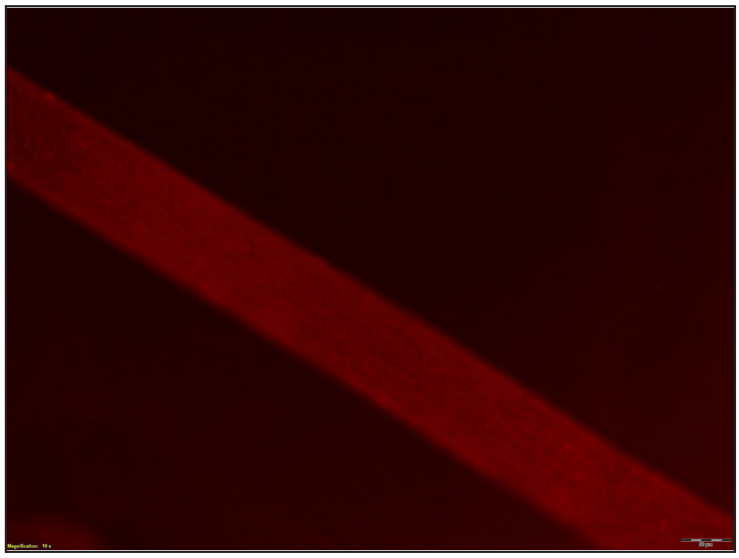
x10 magnification

Brightfield image combined with hoechst stained cell images - composite image
24hrs post seeding



x10 magnification

Brightfield image combined with red cell images - composite image (same view as above)
24hrs post seeding



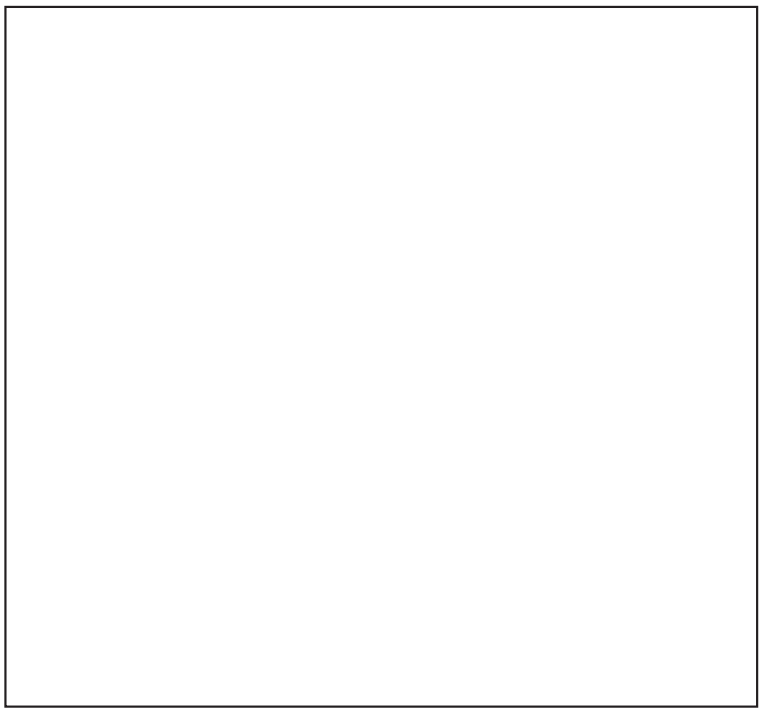
NOTES

- The horsehair had very few cells adhered.
- It appears that the gelatin coating did not help make the material more attractive for cell attachment. There were some cells that appeared to show up with the hoechst dye, but the same image in red shows no cells.

Milk

Milk

MATERIAL SAMPLE



MATERIAL SIZE

350 microns (0.35mm)

MATERIAL STRUCTURE

Hand spun, single ply

NOTES

- Fabric source: http://handweavers.co.uk/shop/milk-protein-tops-milk_protein_top.html#SID=169
- Fibre was very 'wetable' i.e. absorbs water quickly and does not float
- Autofluorescence - auto-fluoresces in red and green

Experiment 1

DATE	25.01.2016
CELL TYPE	HUVECs *(Human umbilical vein endothelial cells)*
MEDIA TYPE	Endothelial Growth Media 2 (EGM2) *Made by Promocell*
MATERIALS SEEDED	Cotton, Horsehair, Milk, Mohair, Nylon Monofilament, Polyester, SeaCell, Silk, Silk/Steel, Soya

AIM

To assess cell adherence, viability and orientation on a range of 10 different yarns

---

PROTOCOL

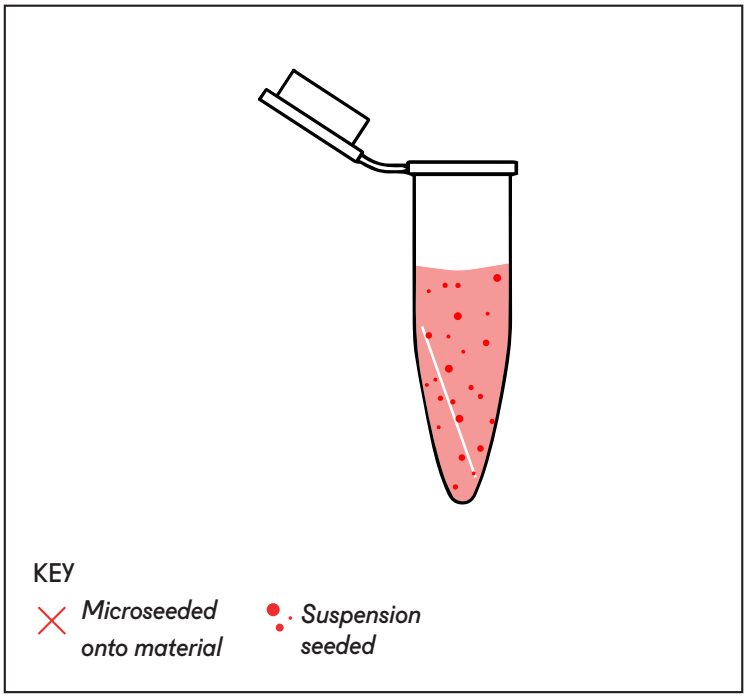
SEEDING

- Grow sufficient number of HUVEC cells to be able to seed all materials - for this experiment each material needs 50,000 cells
- Using sterile tweezers transfer autoclaved material samples into separate eppendorf tubes
- Trypsinize cells, count (re-suspended in 5ml media) and make up concentration of 50,000 cells per 100ml (times by the amount needed - in this case 1ml)
- Tag half of the cells (500ml) with Invitrogen C7025 cell tracker and the other half with Invitrogen C34552 cell tracker and then mix so each scaffold has both colour tracked cells
- Pipette 100ml of cell/ media mix into eppendorf with material sample and then add 400ml of media to make up to 500ml in total
- Place closed tubes in shaker at 37 °C, at 600rpm, and leave for 2 hours
- After 2 hours remove materials from eppendorf tubes and place in separate wells of a 24 well plate. Add media from tube to cover sample. Incubate for 24hrs and then fix for imaging

FIXING

- Remove media and add 1ml of PFA to each well, leave for 30 mins
- Remove PFA, add 1ml of PBS to each well, and agitate for 10mins, repeat.
- Place each material sample on a glass slide, add 150ml of moviol and add cover slip, leave to set for 24hrs

SEEDING



NOTES

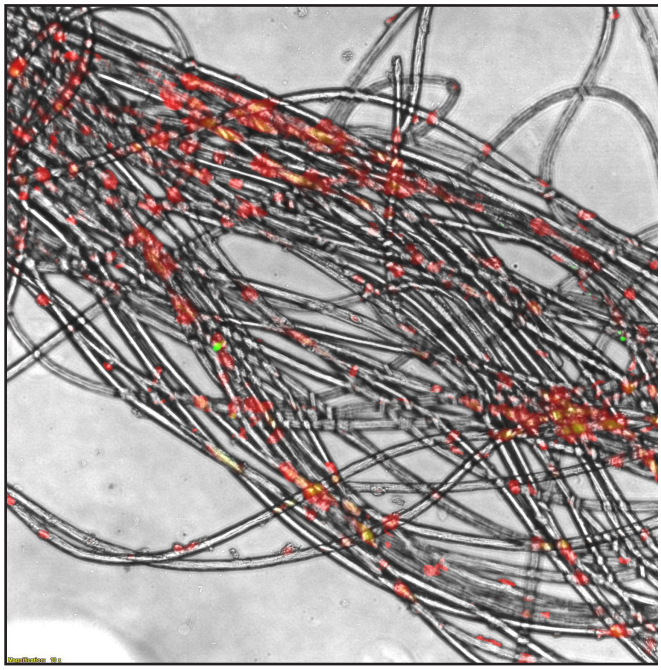
- The different material samples were autoclaved in bags in longer than the required length, they therefore needed cutting down in sterile conditions. This was done by using a sterile petri dish and scalpel blade - cutting approx. 1cm samples of each material and then transferring these to the eppendorf tubes.

- For ease in future experiments it would be better to cut down the material samples to the correct length and autoclave them in a glass petri dish so they are easily found and picked up by tweezers - small samples tend to be lost in autoclave bags and difficult to retrieve

Results

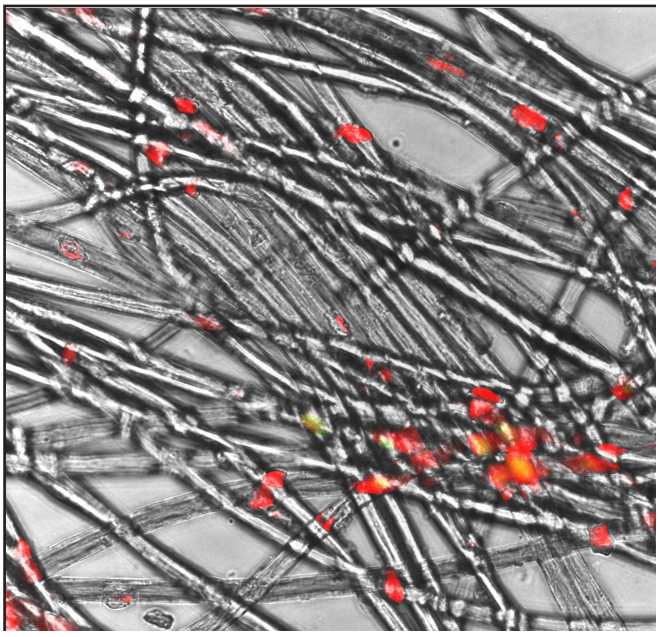
x10 magnification

Brightfield image combined with red & green cell images - composite image 24hrs post seeding



x20 magnification

Brightfield image combined with red & green cell images - composite image 24hrs post seeding



Experiment 2

DATE	01.02.2016
CELL TYPE	HUVECs *(Human umbilical vein endothelial cells)*
MEDIA TYPE	Endothelial Growth Media 2 (EGM2) *Made by Promocell*
MATERIALS SEEDED	Cotton, Horsehair, Milk, Mohair, Nylon Monofilament, Polyester, SeaCell, Silk, Silk/Steel, Soya

AIM

To assess cell adherence, viability and orientation on a range of 10 different yarns pre-coated in gelatin

---

PROTOCOL

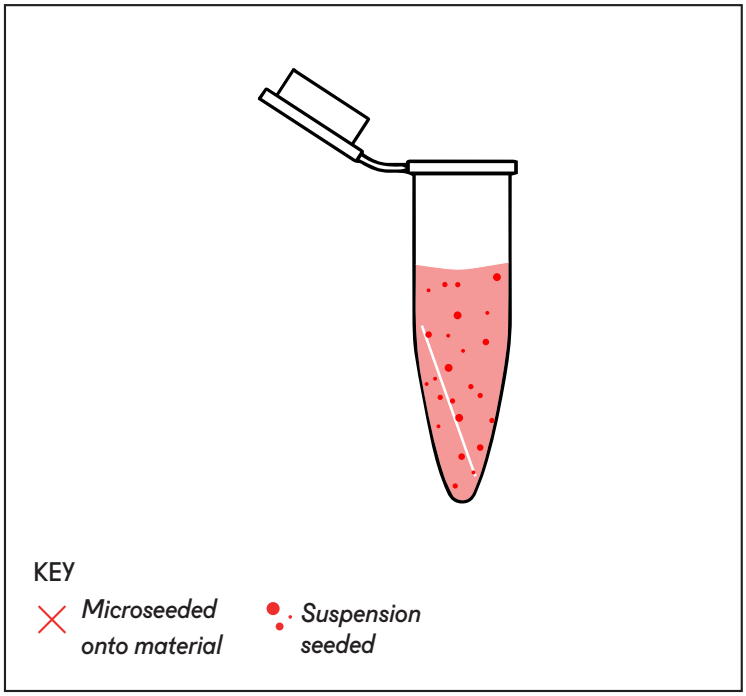
SEEDING

- Grow sufficient number of HUVEC cells to be able to seed all materials - for this experiment each material needs 50,000 cells
- Using sterile tweezers transfer autoclaved material samples into separate eppendorf tubes, the materials were soaked in 0.5% gelatin solution for 24hrs prior to the experiment
- Trypsinize cells, count (re-suspended in 5ml media) and make up concentration of 50,000 cells per 100ml (times by the amount needed - in this case 1ml)
- Tag cells (500ml) with Invitrogen C34552 cell tracker
- Pipette 100ml of cell/ media mix into eppendorf with material sample and then add 400ml of media to make up to 500ml in total
- Place closed tubes in shaker at 37 °C, at 600rpm, and leave for 2 hours
- After 2 hours remove materials from eppendorf tubes and place in separate wells of a 24 well plate. Add media from tube to cover sample. Incubate for 24hrs and then fix for imaging

FIXING

- Remove media and add 1ml of PFA to each well, leave for 30 mins
- Remove PFA, add 1ml of PBS to each well, and agitate for 10mins, repeat.
- Place each material sample on a glass slide, add 150ml of moviol and add cover slip, leave to set for 24hrs

SEEDING



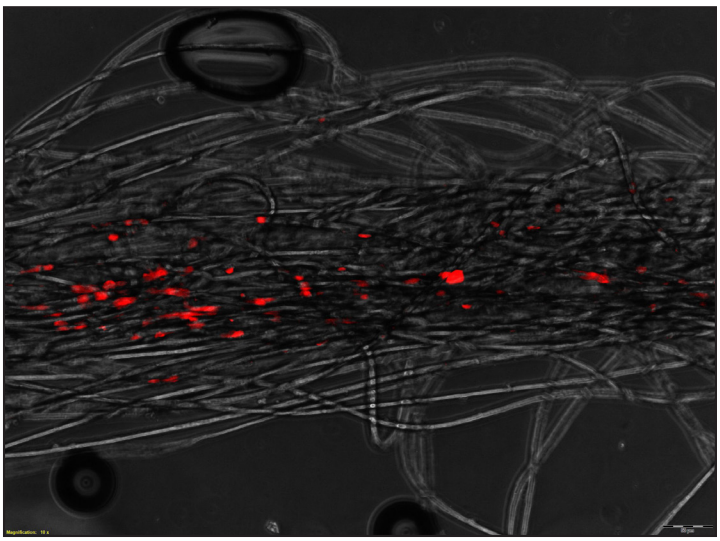
NOTES

- The different material samples were cut to 1cm in length and autoclaved in small glass petri dishes.
- All samples were coated in gelatin prior to seeding to assess if this would improve adherance. The yarns can then be compared to those of experiment 1.
- Only one cell tracker was used, Invitrogen C34552, as it had the least crossover when imaging

Results

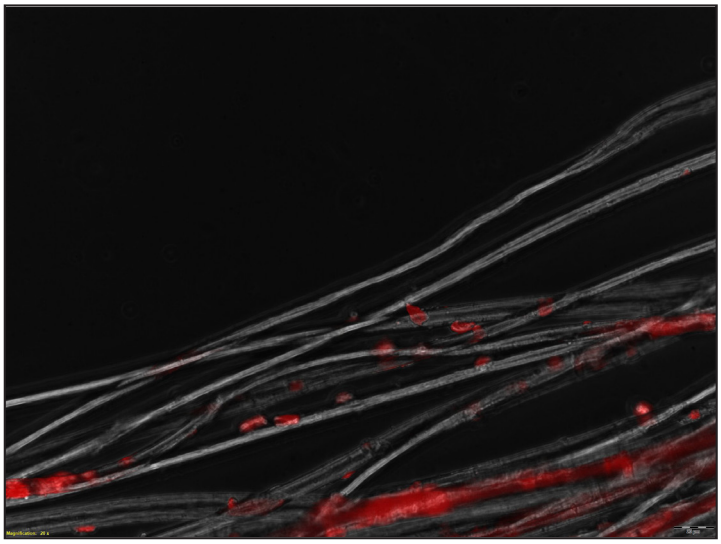
x20 magnification

Brightfield image combined with red cell images - composite image
24hrs post seeding



x20 magnification

Brightfield image combined with red cell images - composite image
24hrs post seeding



NOTES

- The milk fibre was very biologically compatible, out of the 10 other materials it was tested alongside SeaCell it had the second most cells adhered.
- There was some indication that the gelatin made the milk more attractive to the cells, but in both iterations of the experiment there were a good number of cells visible

Experiment 3

DATE	19.04.2016
CELL TYPE	HDFBs *(Human dermal fibroblast (skin) cells)*
MEDIA TYPE	K45 Fib GM Media *Made by Promocell*
MATERIALS SEEDED	Milk & SeaCell

AIM

To assess adherence, of a different cell type, on the two most biologically compatible materials

---

PROTOCOL

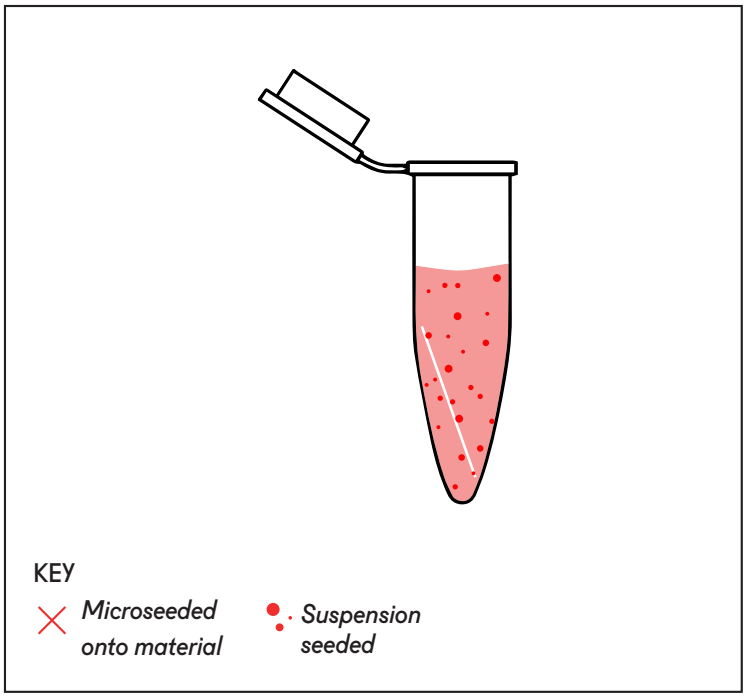
SEEDING

- Grow sufficient number of HDFB cells to be able to seed all materials - for this experiment each material needs 50,000 cells
- Using sterile tweezers transfer autoclaved material samples into separate eppendorf tubes
- Trypsinize cells, count (re-suspended in 5ml media) and make up concentration of 50,000 cells per 100ml (times by the amount needed - in this case 1ml)
- Tag cells with Invitrogen C34552 cell tracker
- Pipette 100ml of cell/ media mix into eppendorf with material sample and then add 400ml of media to make up to 500ml in total
- Place closed tubes in shaker at 37 °C, at 600rpm, and leave for 2 hours
- After 2 hours remove materials from eppendorf tubes and place in separate wells of a 24 well plate. Add media from tube to cover sample. Incubate for 24hrs and then fix for imaging

FIXING

- Remove media and add 1ml of PFA to each well, leave for 30 mins
- Remove PFA, add 1ml of PBS to each well, and agitate for 10mins, repeat.
- Place each material sample on a glass slide, add 150ml of moviol and add cover slip, leave to set for 24hrs

SEEDING



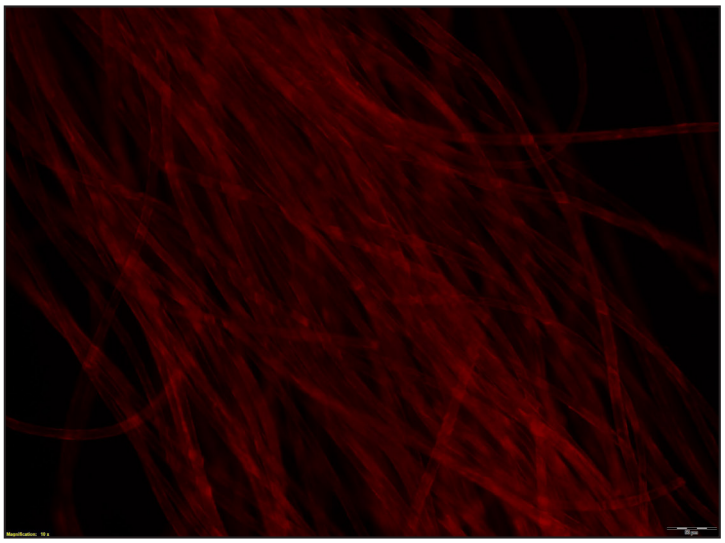
NOTES

- The different material samples were cut to 1cm in length and autoclaved in small glass petri dishes.
- Only one cell tracker was used, Invitrogen C34552, as it had the least crossover when imaging

Results

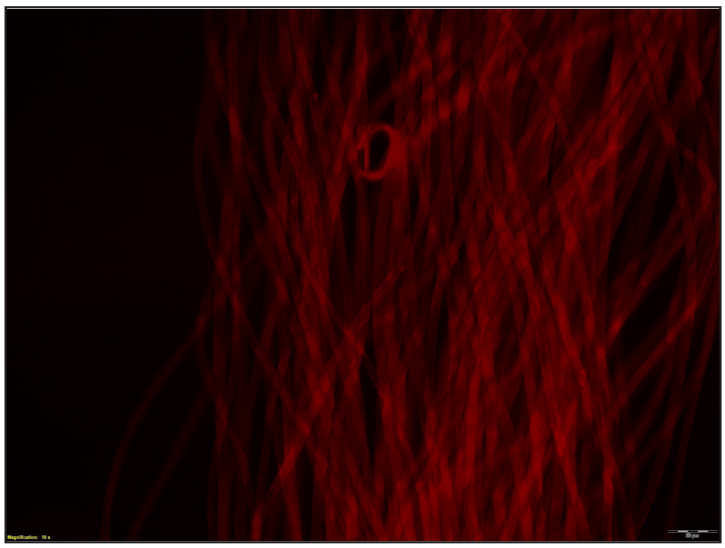
x10 magnification

Red cell image
24hrs post seeding



x10 magnification

Red cell image
24hrs post seeding



NOTES

- No cells were visible after 24 hours seeding
- This experiment was a repeat of a previous attempt using HDFB cells which was unsuccessful due to a problem with the cells used. It is possible this is the cause again, but there were cells visible on the SeaCell, so another possible cause is that there may have been a issue during seeding.

Experiment 4

DATE	20.04.2016
CELL TYPE	C2C12s *(immortalized mouse myoblast (muscle) cells)*
MEDIA TYPE	DMEM X1 + GlutaMAX *Made by Gibco*
MATERIALS SEEDED	Milk & SeaCell

AIM

To assess adherence, of a different cell type, on the two most biologically compatible materials

---

PROTOCOL

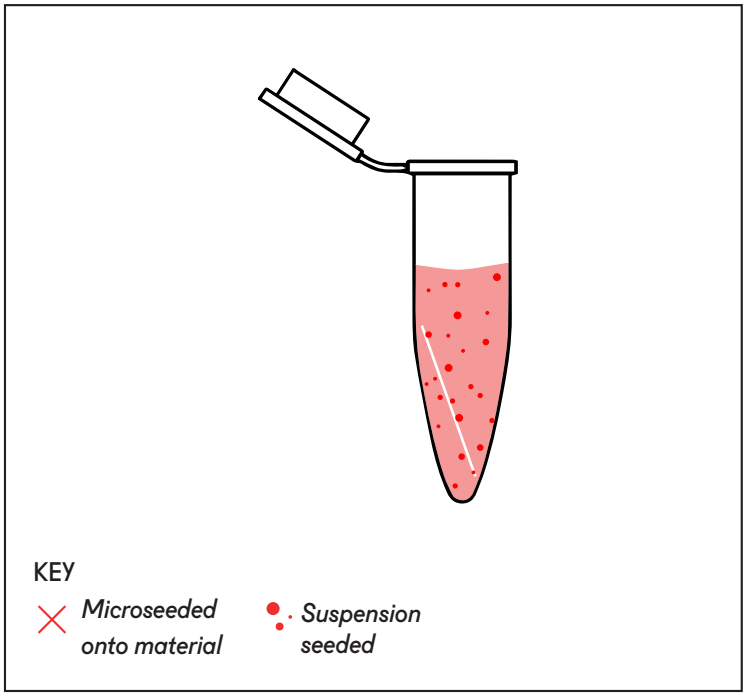
SEEDING

- Grow sufficient number of C2C12 cells to be able to seed all materials - for this experiment each material needs 50,000 cells
- Using sterile tweezers transfer autoclaved material samples into separate eppendorf tubes, the materials were soaked in 0.5% gelatin solution for 24hrs prior to the experiment
- Trypsinize cells, count (re-suspended in 5ml media) and make up concentration of 50,000 cells per 100ml (times by the amount needed - in this case 1ml)
- Tag cells with Invitrogen C34552 cell tracker
- Pipette 100ml of cell/ media mix into eppendorf with material sample and then add 400ml of media to make up to 500ml in total
- Place closed tubes in shaker at 37 °C, at 600rpm, and leave for 2 hours
- After 2 hours remove materials from eppendorf tubes and place in separate wells of a 24 well plate. Add media from tube to cover sample. Incubate for 24hrs and then fix for imaging

FIXING

- Remove media and add 1ml of PFA to each well, leave for 30 mins
- Remove PFA, add 1ml of PBS to each well, and agitate for 10mins, repeat.
- Place each material sample on a glass slide, add 150ml of moviol and add cover slip, leave to set for 24hrs

SEEDING



NOTES

- The different material samples were cut to 1cm in length and autoclaved in small glass petri dishes.
- All samples were coated in gelatin prior to seeding to assess if this would improve adherance. The yarns can then be compared to those of experiment 1.
- Only one cell tracker was used, Invitrogen C34552, as it had the least crossover when imaging

Results

NOTES

- Images lost - problem with software
- Good number of cells attached, some rounded and with some elongated along individual fibres

Experiment 5

DATE	13.07.2016
CELL TYPE	C2C12s *(immortalized mouse myoblast (muscle) cells)*
MEDIA TYPE	DMEM X1 + GlutaMAX *Made by Gibco*
MATERIALS SEEDED	Milk & SeaCell

AIM

Repeat experiment to assess cell adherence on Milk and SeaCell threads

---

PROTOCOL

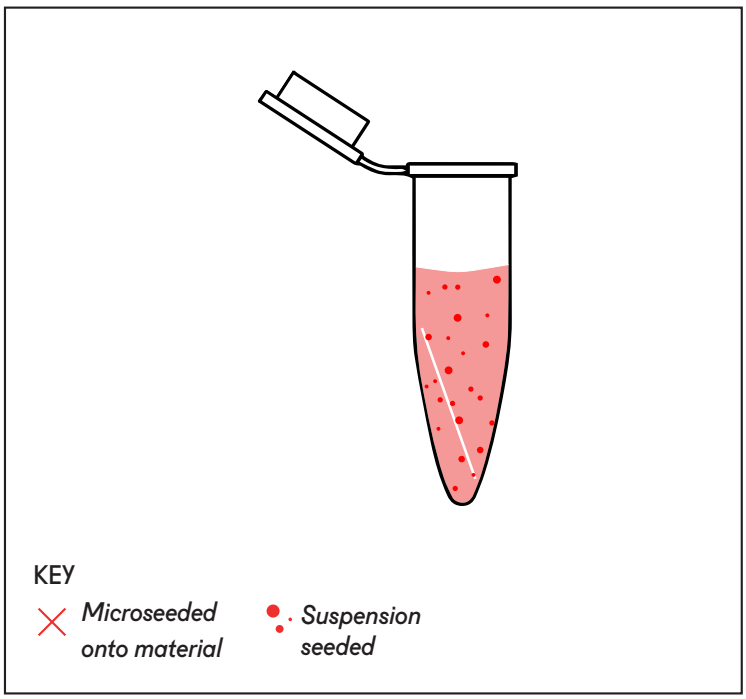
SEEDING

- Grow sufficient number of C2C12 cells to be able to seed all materials - for this experiment each material needs 50,000 cells
- Using sterile tweezers transfer autoclaved material samples into separate eppendorf tubes, the materials were soaked in 0.5% gelatin solution for 24hrs prior to the experiment
- Trypsinize cells, count (re-suspended in 5ml media) and make up concentration of 50,000 cells per 100ml (times by the amount needed - in this case 1ml)
- Pipette 100ml of cell/ media mix into eppendorf with material sample and then add 400ml of media to make up to 500ml in total
- Place closed tubes in shaker at 37 °C, at 600rpm, and leave for 2 hours
- After 2 hours remove materials from eppendorf tubes and place in separate wells of a 24 well plate. Add media from tube to cover sample. Incubate for 24hrs and then fix for imaging

FIXING

- Remove media and add 1ml of PFA to each well, leave for 30 mins
- Remove PFA, add 1ml of PBS to each well, and agitate for 10mins, repeat.
- Add 1µL of phaloid stain to 1ml of PBS - add to each well, cover in foil and shake for 30 mins
- Place each material sample on a glass slide, add 150ml of moviol and add cover slip, leave to set for 24hrs

SEEDING



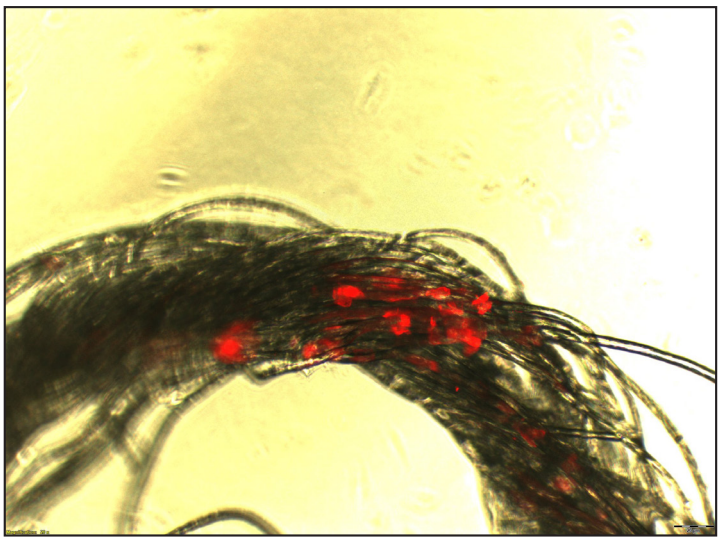
NOTES

- The different material samples were cut to 1cm in length and autoclaved in small glass petri dishes.
- All samples were coated in gelatin prior to seeding improve cell adherance.
- No cell tracker was used in this experiment, instead the cells were stained post fixing with Phaloid stain.

Results

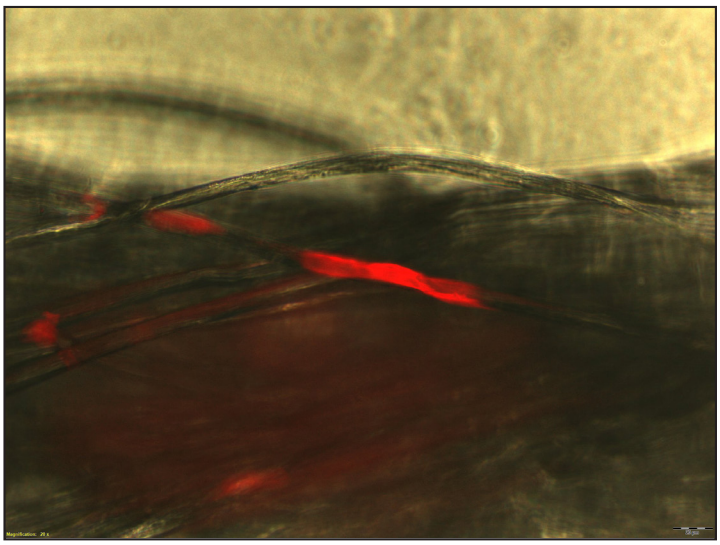
x10 magnification

Brightfield image combined with red cell images - composite image
24hrs post seeding



x20 magnification

Brightfield image combined with red cell images - composite image
24hrs post seeding



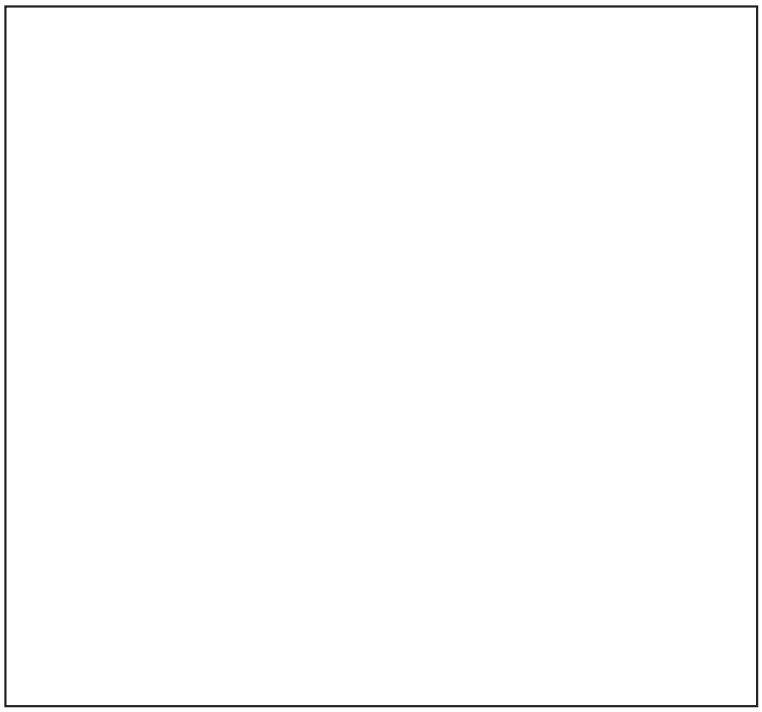
NOTES

- The milk fibre is very biologically compatible, but does not appear to have as many cells attached as SeaCell thread
- The muscle cells, in some areas, elongated along the length of the fibres which make up the thread - see above image.

Mohair

Mohair

MATERIAL SAMPLE



MATERIAL SIZE

600 microns (0.6mm) (32 microns single fibre)

MATERIAL STRUCTURE

2 ply, S twist

NOTES

- Fabric source:
  https://www.handweavers.co.uk/yarns-mohair
- Fibre was extremely 'wetable'
- Autofluorescence - material auto-fluoresced slightly under both green and red

Experiment 1

DATE	25.01.2016
CELL TYPE	HUVECs *(Human umbilical vein endothelial cells)*
MEDIA TYPE	Endothelial Growth Media 2 (EGM2) *Made by Promocell*
MATERIALS SEEDED	Cotton, Horsehair, Milk, Mohair, Nylon Monofilament, Polyester, SeaCell, Silk, Silk/Steel, Soya

AIM

To assess cell adherence, viability and orientation on a range of 10 different yarns

---

PROTOCOL

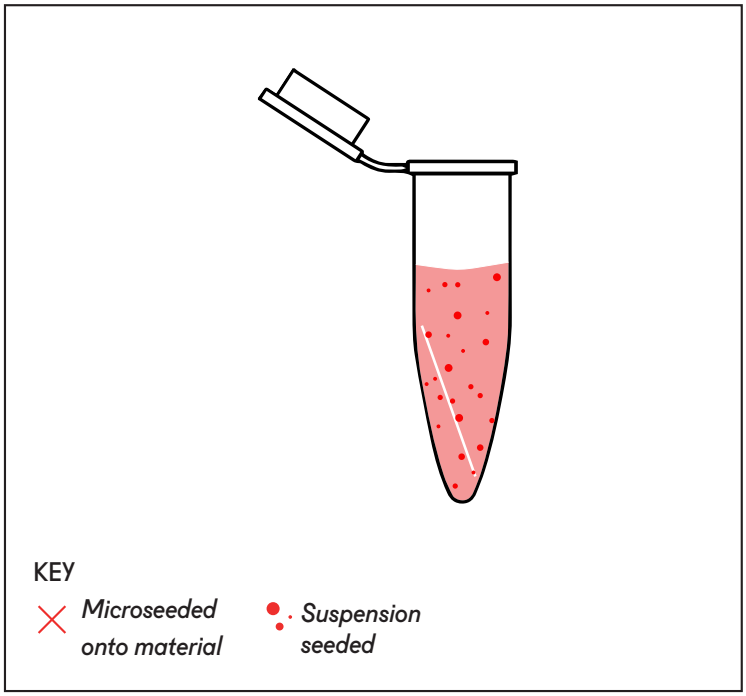
SEEDING

- Grow sufficient number of HUVEC cells to be able to seed all materials - for this experiment each material needs 50,000 cells
- Using sterile tweezers transfer autoclaved material samples into separate eppendorf tubes
- Trypsinize cells, count (re-suspended in 5ml media) and make up concentration of 50,000 cells per 100ml (times by the amount needed - in this case 1ml)
- Tag half of the cells (500ml) with Invitrogen C7025 cell tracker and the other half with Invitrogen C34552 cell tracker and then mix so each scaffold has both colour tracked cells
- Pipette 100ml of cell/ media mix into eppendorf with material sample and then add 400ml of media to make up to 500ml in total
- Place closed tubes in shaker at 37 °C, at 600rpm, and leave for 2 hours
- After 2 hours remove materials from eppendorf tubes and place in separate wells of a 24 well plate. Add media from tube to cover sample. Incubate for 24hrs and then fix for imaging

FIXING

- Remove media and add 1ml of PFA to each well, leave for 30 mins
- Remove PFA, add 1ml of PBS to each well, and agitate for 10mins, repeat.
- Place each material sample on a glass slide, add 150ml of moviol and add cover slip, leave to set for 24hrs

SEEDING



NOTES

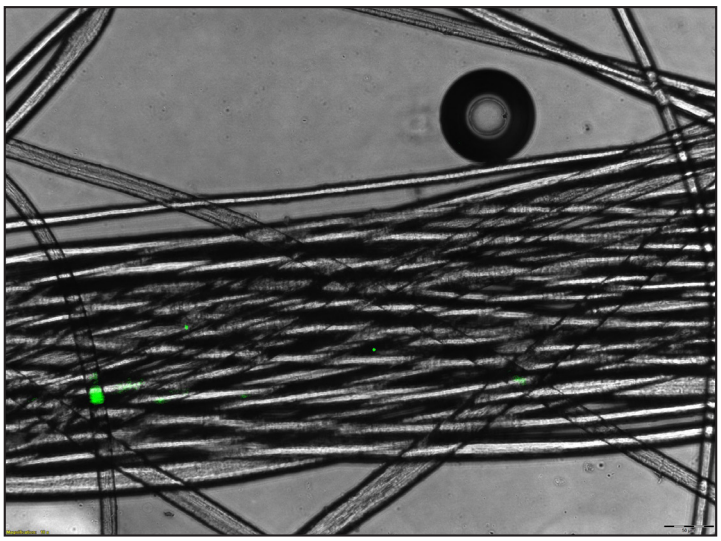
- The different material samples were autoclaved in bags in longer than the required length, they therefore needed cutting down in sterile conditions. This was done by using a sterile petri dish and scalpel blade - cutting approx. 1cm samples of each material and then transferring these to the eppendorf tubes.

- For ease in future experiments it would be better to cut down the material samples to the correct length and autoclave them in a glass petri dish so they are easily found and picked up by tweezers - small samples tend to be lost in autoclave bags and difficult to retrieve

Results

x10 magnification

Brightfield image combined with red & green cell images - composite image 24hrs post seeding



NOTES

- Only a couple of cells visible
- Small and rounded which suggest they may be trapped rather than properly attached to the fibres

Experiment 2

DATE	01.02.2016
CELL TYPE	HUVECs *(Human umbilical vein endothelial cells)*
MEDIA TYPE	Endothelial Growth Media 2 (EGM2) *Made by Promocell*
MATERIALS SEEDED	Cotton, Horsehair, Milk, Mohair, Nylon Monofilament, Polyester, SeaCell, Silk, Silk/Steel, Soya

AIM

To assess cell adherence, viability and orientation on a range of 10 different yarns pre-coated in gelatin

---

PROTOCOL

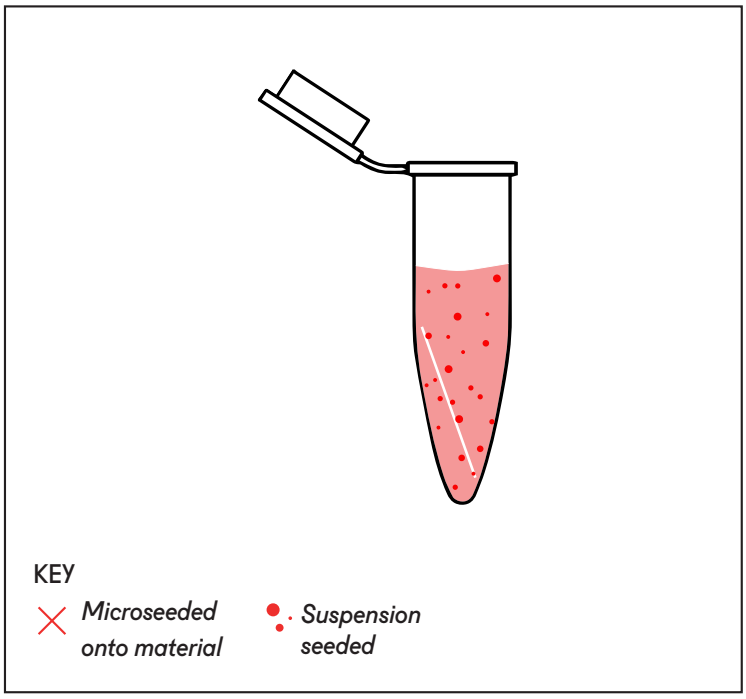
SEEDING

- Grow sufficient number of HUVEC cells to be able to seed all materials - for this experiment each material needs 50,000 cells
- Using sterile tweezers transfer autoclaved material samples into separate eppendorf tubes, the materials were soaked in 0.5% gelatin solution for 24hrs prior to the experiment
- Trypsinize cells, count (re-suspended in 5ml media) and make up concentration of 50,000 cells per 100ml (times by the amount needed - in this case 1ml)
- Tag cells with Invitrogen C34552 cell tracker
- Pipette 100ml of cell/ media mix into eppendorf with material sample and then add 400ml of media to make up to 500ml in total
- Place closed tubes in shaker at 37 °C, at 600rpm, and leave for 2 hours
- After 2 hours remove materials from eppendorf tubes and place in separate wells of a 24 well plate. Add media from tube to cover sample. Incubate for 24hrs and then fix for imaging

FIXING

- Remove media and add 1ml of PFA to each well, leave for 30 mins
- Remove PFA, add 1ml of PBS to each well, and agitate for 10mins, repeat.
- Place each material sample on a glass slide, add 150ml of moviol and add cover slip, leave to set for 24hrs

SEEDING



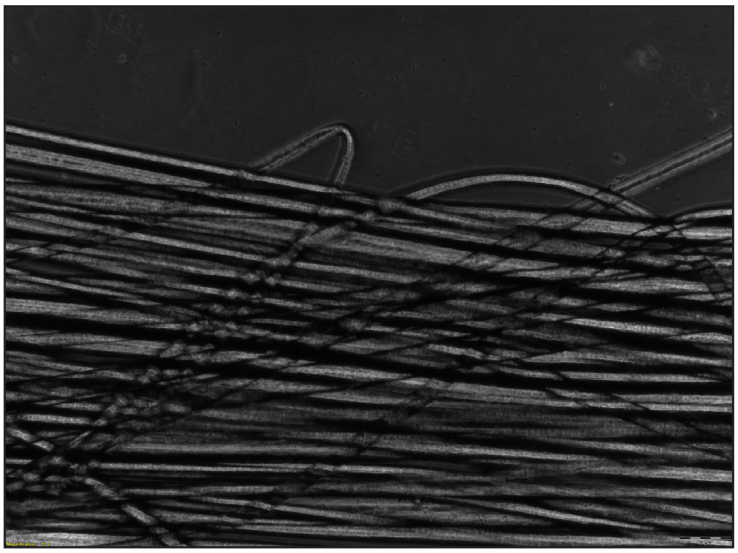
NOTES

- The different material samples were cut to 1cm in length and autoclaved in small glass petri dishes.
- All samples were coated in gelatin prior to seeding to assess if this would improve adherance. The yarns can then be compared to those of experiment 1.
- Only one cell tracker was used, Invitrogen C34552, as it had the least crossover when imaging

Results

x20 magnification

Brightfield image combined with red cell images - composite image
24hrs post seeding



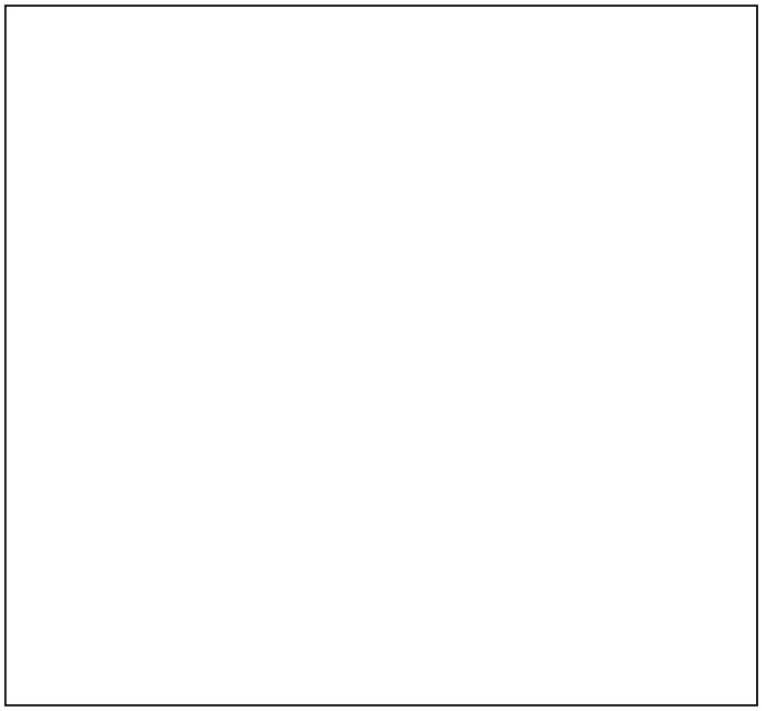
NOTES

- No cells visible

Nylon Monofilament

Nylon Monofilament

MATERIAL SAMPLE



MATERIAL SIZE

300 microns (0.3mm)

MATERIAL STRUCTURE

Monofilament

NOTES

- Fabric source:
  'Climax High Quality Filament' http://modelshop.co.uk/
- Fibre was 'wetable', in that it didn't float. However, it cannot absorb liquid and therefore media and proteins
- Autofluorescence - material fluoresced under green, and slightly under red

Experiment 1

DATE	25.01.2016
CELL TYPE	HUVECs *(Human umbilical vein endothelial cells)*
MEDIA TYPE	Endothelial Growth Media 2 (EGM2) *Made by Promocell*
MATERIALS SEEDED	Cotton, Horsehair, Milk, Mohair, Nylon Monofilament, Polyester, SeaCell, Silk, Silk/Steel, Soya

AIM

To assess cell adherence, viability and orientation on a range of 10 different yarns

---

PROTOCOL

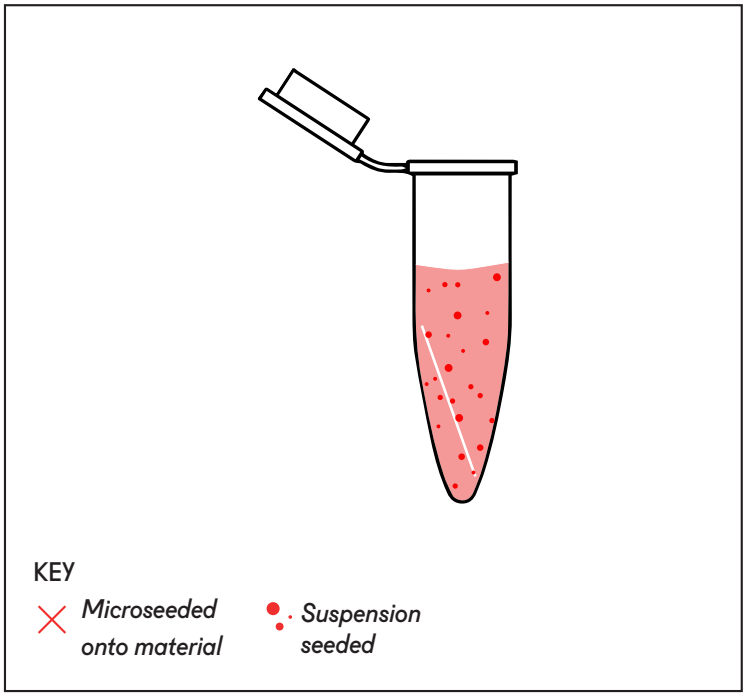
SEEDING

- Grow sufficient number of HUVEC cells to be able to seed all materials - for this experiment each material needs 50,000 cells
- Using sterile tweezers transfer autoclaved material samples into separate eppendorf tubes
- Trypsinize cells, count (re-suspended in 5ml media) and make up concentration of 50,000 cells per 100ml (times by the amount needed - in this case 1ml)
- Tag half of the cells (500ml) with Invitrogen C7025 cell tracker and the other half with Invitrogen C34552 cell tracker and then mix so each scaffold has both colour tracked cells
- Pipette 100ml of cell/ media mix into eppendorf with material sample and then add 400ml of media to make up to 500ml in total
- Place closed tubes in shaker at 37 °C, at 600rpm, and leave for 2 hours
- After 2 hours remove materials from eppendorf tubes and place in separate wells of a 24 well plate. Add media from tube to cover sample. Incubate for 24hrs and then fix for imaging

FIXING

- Remove media and add 1ml of PFA to each well, leave for 30 mins
- Remove PFA, add 1ml of PBS to each well, and agitate for 10mins, repeat.
- Place each material sample on a glass slide, add 150ml of moviol and add cover slip, leave to set for 24hrs

SEEDING



NOTES

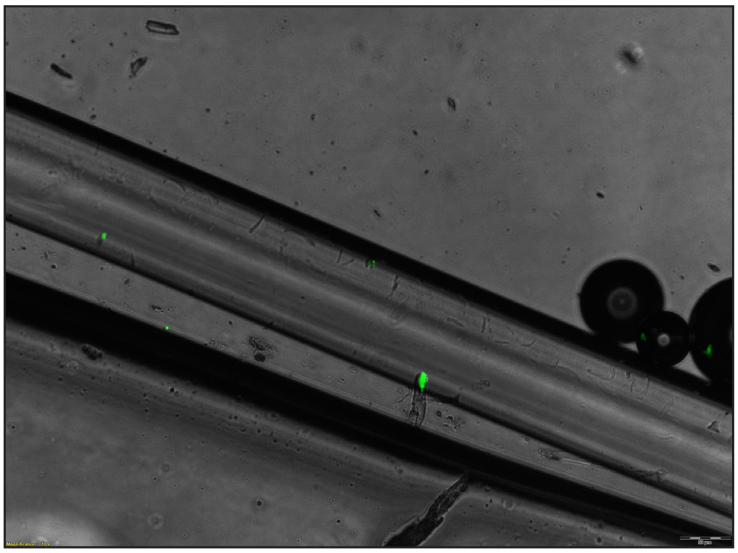
- The different material samples were autoclaved in bags in longer than the required length, they therefore needed cutting down in sterile conditions. This was done by using a sterile petri dish and scalpel blade - cutting approx. 1cm samples of each material and then transferring these to the eppendorf tubes.

- For ease in future experiments it would be better to cut down the material samples to the correct length and autoclave them in a glass petri dish so they are easily found and picked up by tweezers - small samples tend to be lost in autoclave bags and difficult to retrieve

Results

x10 magnification

Brightfield image combined with red & green cell images - composite image 24hrs post seeding



NOTES

- No cells visible on filament
- Small green dot seen in this image is floating above thread

Experiment 2

DATE	01.02.2016
CELL TYPE	HUVECs *(Human umbilical vein endothelial cells)*
MEDIA TYPE	Endothelial Growth Media 2 (EGM2) *Made by Promocell*
MATERIALS SEEDED	Cotton, Horsehair, Milk, Mohair, Nylon Monofilament, Polyester, SeaCell, Silk, Silk/Steel, Soya

AIM

To assess cell adherence, viability and orientation on a range of 10 different yarns pre-coated in gelatin

---

PROTOCOL

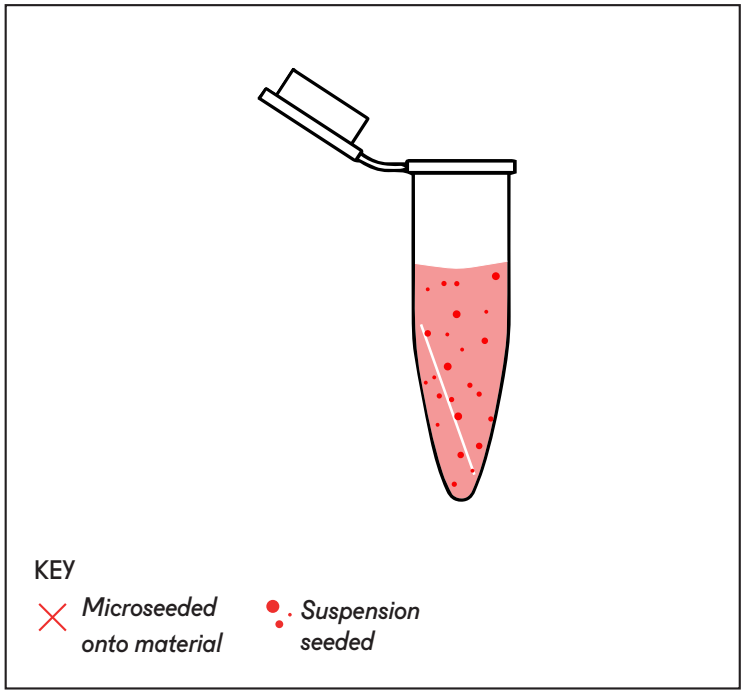
SEEDING

- Grow sufficient number of HUVEC cells to be able to seed all materials - for this experiment each material needs 50,000 cells
- Using sterile tweezers transfer autoclaved material samples into separate eppendorf tubes, the materials were soaked in 0.5% gelatin solution for 24hrs prior to the experiment
- Trypsinize cells, count (re-suspended in 5ml media) and make up concentration of 50,000 cells per 100ml (times by the amount needed - in this case 1ml)
- Tag cells with Invitrogen C34552 cell tracker
- Pipette 100ml of cell/ media mix into eppendorf with material sample and then add 400ml of media to make up to 500ml in total
- Place closed tubes in shaker at 37 °C, at 600rpm, and leave for 2 hours
- After 2 hours remove materials from eppendorf tubes and place in separate wells of a 24 well plate. Add media from tube to cover sample. Incubate for 24hrs and then fix for imaging

*F*IXING

- Remove media and add 1ml of PFA to each well, leave for 30 mins
- Remove PFA, add 1ml of PBS to each well, and agitate for 10mins, repeat.
- Cells were also Hoechst stained to mark cell nuclei
- Place each material sample on a glass slide, add 150ml of moviol and add cover slip, leave to set for 24hrs

SEEDING



NOTES

- The different material samples were cut to 1cm in length and autoclaved in small glass petri dishes.
- All samples were coated in gelatin prior to seeding to assess if this would improve adherance. The yarns can then be compared to those of experiment 1.
- Only one cell tracker was used, Invitrogen C34552, as it had the least crossover when imaging

Results

x20 magnification

Brightfield image combined with red cell images - composite image
24hrs post seeding

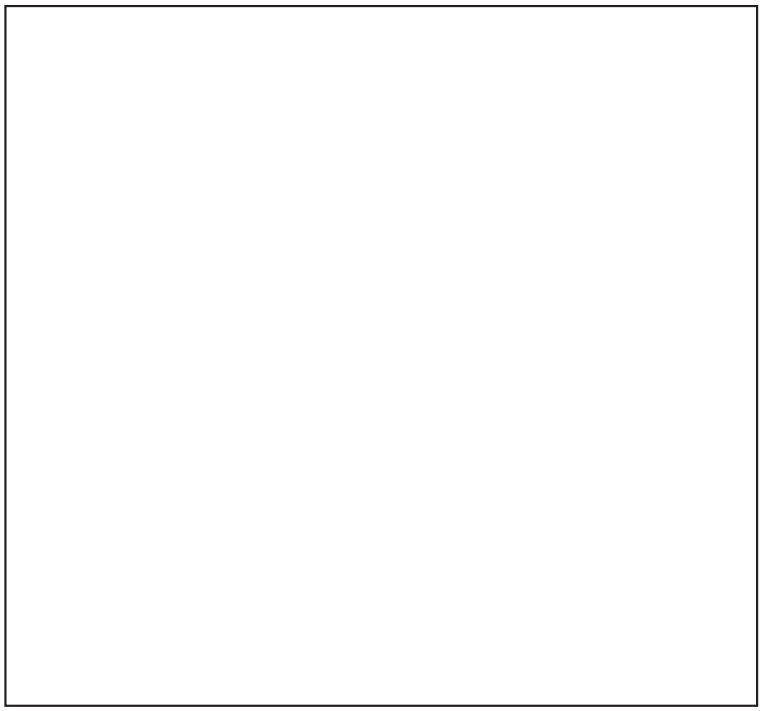
NOTES

- No cells visible

Polyester

Polyester

MATERIAL SAMPLE



MATERIAL SIZE	300 microns (0.3mm)
MATERIAL STRUCTURE	2 ply, Z twist
NOTES	• Fabric source: https://www.guetermann.com/ • Fibre was slightly 'wetable', but will not absorb water and therefore media and proteins • Autofluorescence - auto-fluoresces slightly under both green and red

Experiment 1

DATE	25.01.2016
CELL TYPE	HUVECs *(Human umbilical vein endothelial cells)*
MEDIA TYPE	Endothelial Growth Media 2 (EGM2) *Made by Promocell*
MATERIALS SEEDED	Cotton, Horsehair, Milk, Mohair, Nylon Monofilament, Polyester, SeaCell, Silk, Silk/Steel, Soya

AIM

To assess cell adherence, viability and orientation on a range of 10 different yarns

---

PROTOCOL

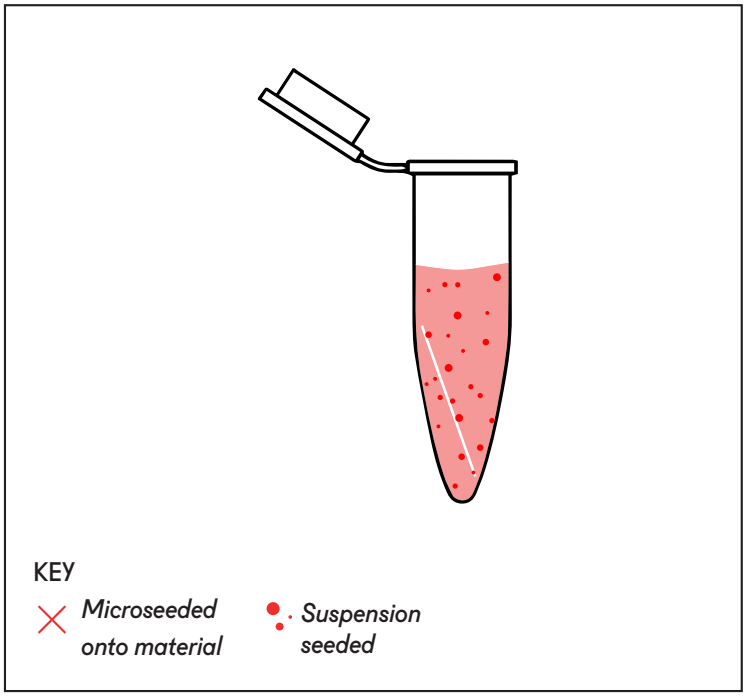
SEEDING

- Grow sufficient number of HUVEC cells to be able to seed all materials - for this experiment each material needs 50,000 cells
- Using sterile tweezers transfer autoclaved material samples into separate eppendorf tubes
- Trypsinize cells, count (re-suspended in 5ml media) and make up concentration of 50,000 cells per 100ml (times by the amount needed - in this case 1ml)
- Tag half of the cells (500ml) with Invitrogen C7025 cell tracker and the other half with Invitrogen C34552 cell tracker and then mix so each scaffold has both colour tracked cells
- Pipette 100ml of cell/ media mix into eppendorf with material sample and then add 400ml of media to make up to 500ml in total
- Place closed tubes in shaker at 37 °C, at 600rpm, and leave for 2 hours
- After 2 hours remove materials from eppendorf tubes and place in separate wells of a 24 well plate. Add media from tube to cover sample. Incubate for 24hrs and then fix for imaging

FIXING

- Remove media and add 1ml of PFA to each well, leave for 30 mins
- Remove PFA, add 1ml of PBS to each well, and agitate for 10mins, repeat.
- Place each material sample on a glass slide, add 150ml of moviol and add cover slip, leave to set for 24hrs

SEEDING



NOTES

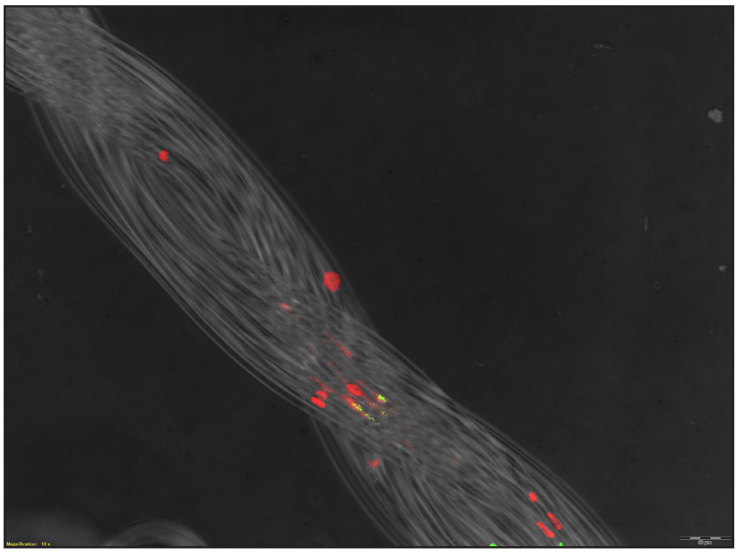
- The different material samples were autoclaved in bags in longer than the required length, they therefore needed cutting down in sterile conditions. This was done by using a sterile petri dish and scalpel blade - cutting approx. 1cm samples of each material and then transferring these to the eppendorf tubes.

- For ease in future experiments it would be better to cut down the material samples to the correct length and autoclave them in a glass petri dish so they are easily found and picked up by tweezers - small samples tend to be lost in autoclave bags and difficult to retrieve

Results

x10 magnification

Brightfield image combined with red & green cell images - composite image 24hrs post seeding



NOTES

- A few cells visible
- Some cross over in imaging in different UV light
- Cells are rounded in morphology

Experiment 2

DATE	01.02.2016
CELL TYPE	HUVECs *(Human umbilical vein endothelial cells)*
MEDIA TYPE	Endothelial Growth Media 2 (EGM2) *Made by Promocell*
MATERIALS SEEDED	Cotton, Horsehair, Milk, Mohair, Nylon Monofilament, Polyester, SeaCell, Silk, Silk/Steel, Soya

AIM

To assess cell adherence, viability and orientation on a range of 10 different yarns pre-coated in gelatin

---

PROTOCOL

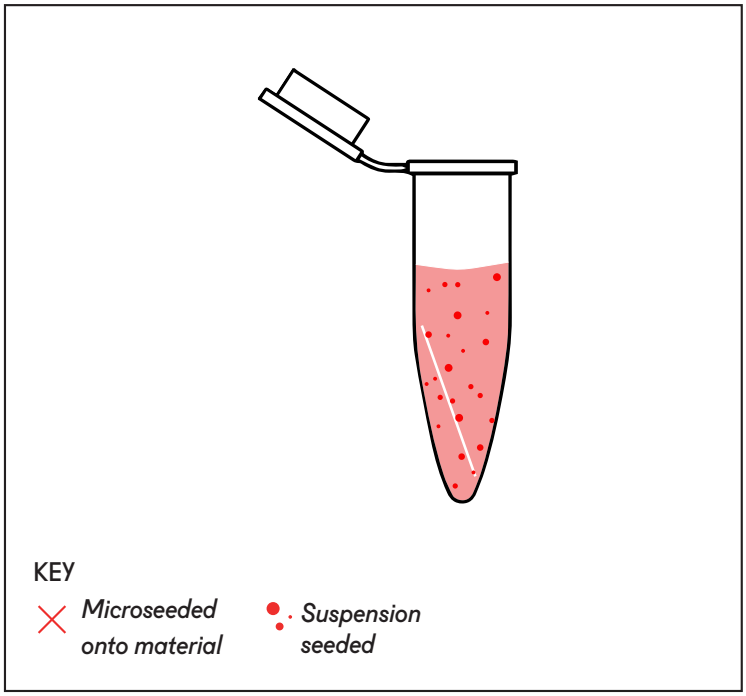
SEEDING

- Grow sufficient number of HUVEC cells to be able to seed all materials - for this experiment each material needs 50,000 cells
- Using sterile tweezers transfer autoclaved material samples into separate eppendorf tubes, the materials were soaked in 0.5% gelatin solution for 24hrs prior to the experiment
- Trypsinize cells, count (re-suspended in 5ml media) and make up concentration of 50,000 cells per 100ml (times by the amount needed - in this case 1ml)
- Tag cells with Invitrogen C34552 cell tracker
- Pipette 100ml of cell/ media mix into eppendorf with material sample and then add 400ml of media to make up to 500ml in total
- Place closed tubes in shaker at 37 °C, at 600rpm, and leave for 2 hours
- After 2 hours remove materials from eppendorf tubes and place in separate wells of a 24 well plate. Add media from tube to cover sample. Incubate for 24hrs and then fix for imaging

FIXING

- Remove media and add 1ml of PFA to each well, leave for 30 mins
- Remove PFA, add 1ml of PBS to each well, and agitate for 10mins, repeat.
- Cells were also Hoechst stained to mark cell nuclei
- Place each material sample on a glass slide, add 150ml of moviol and add cover slip, leave to set for 24hrs

SEEDING



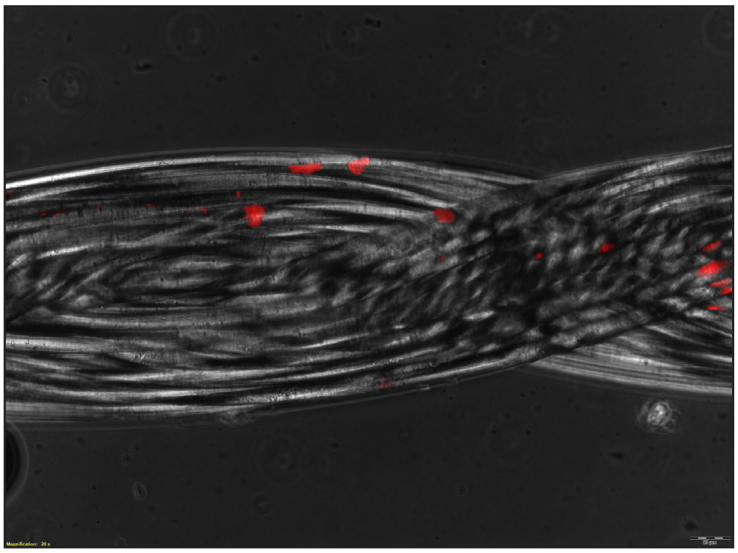
NOTES

- The different material samples were cut to 1cm in length and autoclaved in small glass petri dishes.
- All samples were coated in gelatin prior to seeding to assess if this would improve adherance. The yarns can then be compared to those of experiment 1.
- Only one cell tracker was used, Invitrogen C34552, as it had the least crossover when imaging

Results

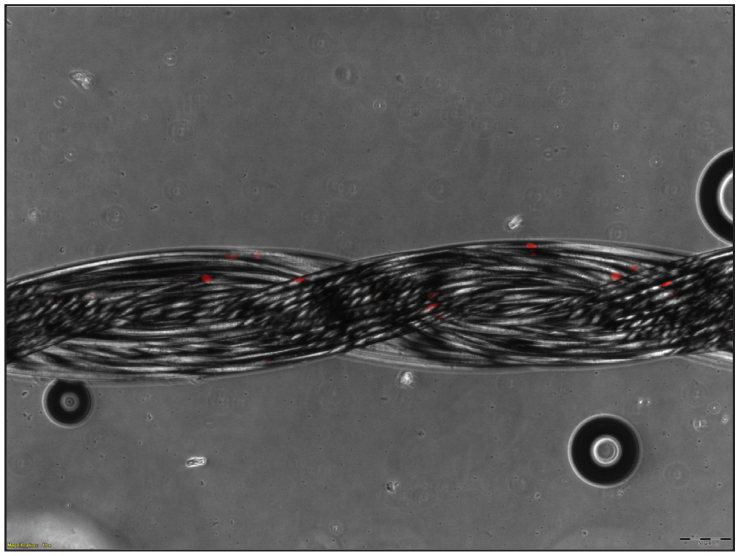
x20 magnification

Brightfield image combined with red cell images - composite image
24hrs post seeding



x10 magnification

Brightfield image combined with red cell images - composite image
24hrs post seeding



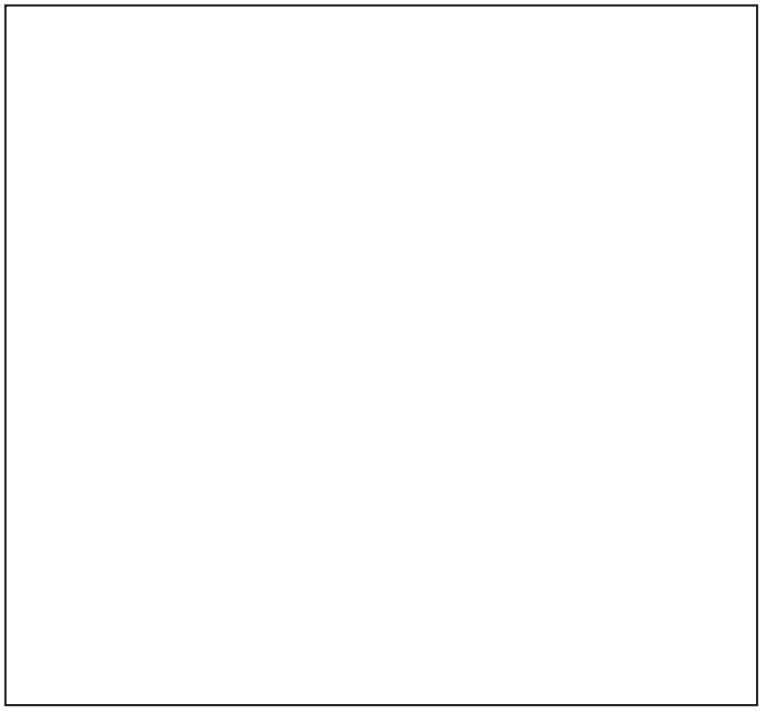
NOTES

- Very few cells visible
- Rounded in morphology

SeaCell

SeaCell

MATERIAL SAMPLE



MATERIAL SIZE	320 microns (0.32mm)
MATERIAL STRUCTURE	Hand spun, single ply
NOTES	• Fabric source: http://handweavers.co.uk/shop/seacell--made-from-seaweed--seacell_top.html#SID=169 • Fibre was the most 'wetable' i.e. absorbs water quickly and does not float • Autofluorescence - does not appear to auto-fluoresce in red or green

Experiment 1

DATE	25.01.2016
CELL TYPE	HUVECs *(Human umbilical vein endothelial cells)*
MEDIA TYPE	Endothelial Growth Media 2 (EGM2) *Made by Promocell*
MATERIALS SEEDED	Cotton, Horsehair, Milk, Mohair, Nylon Monofilament, Polyester, SeaCell, Silk, Silk/Steel, Soya

AIM

To assess cell adherence, viability and orientation on a range of 10 different yarns

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PROTOCOL

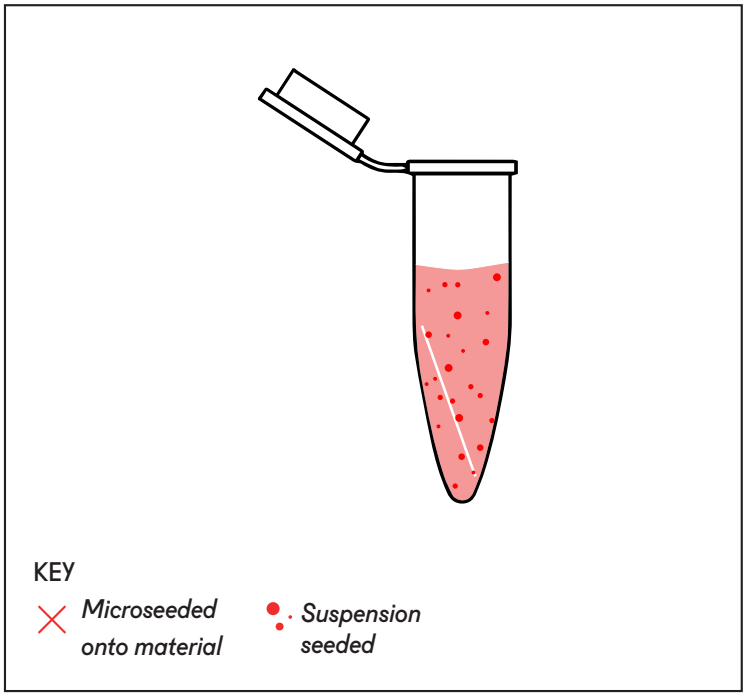
SEEDING

- Grow sufficient number of HUVEC cells to be able to seed all materials - for this experiment each material needs 50,000 cells
- Using sterile tweezers transfer autoclaved material samples into separate eppendorf tubes
- Trypsinize cells, count (re-suspended in 5ml media) and make up concentration of 50,000 cells per 100ml (times by the amount needed - in this case 1ml)
- Tag half of the cells (500ml) with Invitrogen C7025 cell tracker and the other half with Invitrogen C34552 cell tracker and then mix so each scaffold has both colour tracked cells
- Pipette 100ml of cell/ media mix into eppendorf with material sample and then add 400ml of media to make up to 500ml in total
- Place closed tubes in shaker at 37 °C, at 600rpm, and leave for 2 hours
- After 2 hours remove materials from eppendorf tubes and place in separate wells of a 24 well plate. Add media from tube to cover sample. Incubate for 24hrs and then fix for imaging

FIXING

- Remove media and add 1ml of PFA to each well, leave for 30 mins
- Remove PFA, add 1ml of PBS to each well, and agitate for 10mins, repeat.
- Place each material sample on a glass slide, add 150ml of moviol and add cover slip, leave to set for 24hrs

SEEDING



NOTES

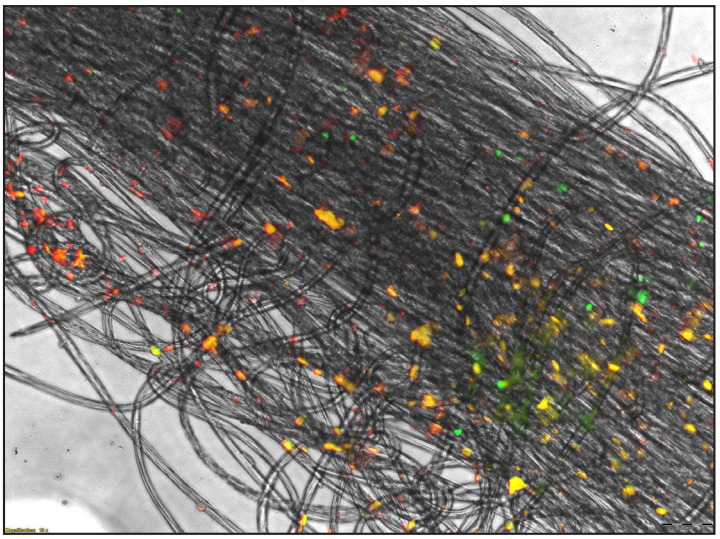
- The different material samples were autoclaved in bags in longer than the required length, they therefore needed cutting down in sterile conditions. This was done by using a sterile petri dish and scalpel blade - cutting approx. 1cm samples of each material and then transferring these to the eppendorf tubes.

- For ease in future experiments it would be better to cut down the material samples to the correct length and autoclave them in a glass petri dish so they are easily found and picked up by tweezers - small samples tend to be lost in autoclave bags and difficult to retrieve

Results

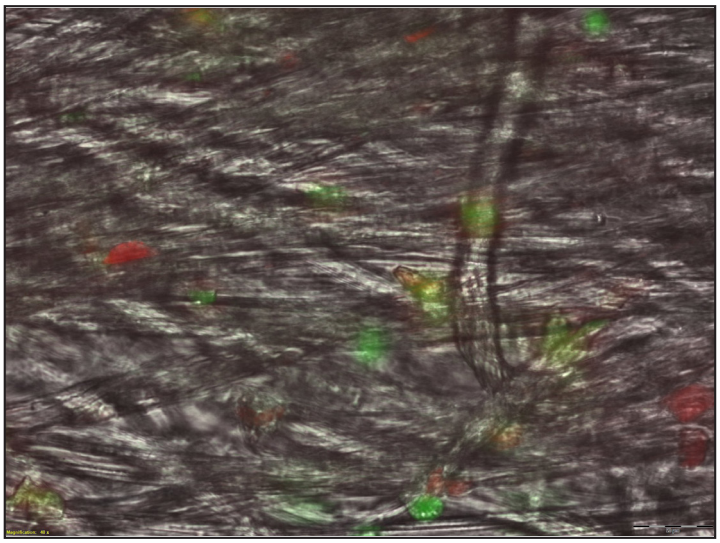
x10 magnification

Brightfield image combined with red & green cell images - composite image 24hrs post seeding



x40 magnification

Brightfield image combined with red & green cell images - composite image 24hrs post seeding



NOTES

- The SeaCell fibre was extremely biologically compatible, out of the 10 materials tested it had the most cells adhered.
- Hand spun yarn unravelled, becoming much looser in the media, despite the thinness of the individual fibres the cells still adhered well to the material - a better yarn structure would be beneficial in any subsequent experiments and for scaffolds.
- During imaging crossover in fluorescence between the red and green markers.

Experiment 2

DATE	01.02.2016
CELL TYPE	HUVECs *(Human umbilical vein endothelial cells)*
MEDIA TYPE	Endothelial Growth Media 2 (EGM2) *Made by Promocell*
MATERIALS SEEDED	Cotton, Horsehair, Milk, Mohair, Nylon Monofilament, Polyester, SeaCell, Silk, Silk/Steel, Soya

AIM

To assess cell adherence, viability and orientation on a range of 10 different yarns pre-coated in gelatin

---

PROTOCOL

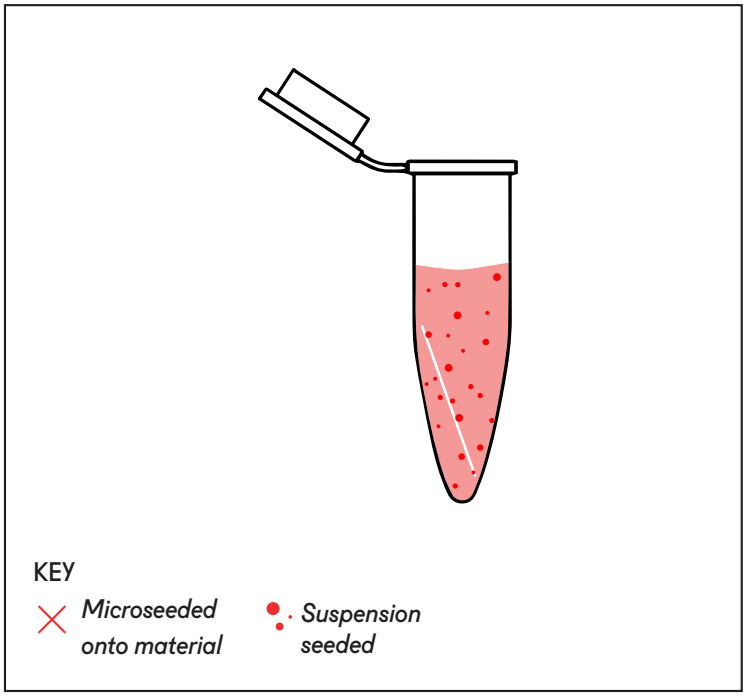
SEEDING

- Grow sufficient number of HUVEC cells to be able to seed all materials - for this experiment each material needs 50,000 cells
- Using sterile tweezers transfer autoclaved material samples into separate eppendorf tubes, the materials were soaked in 0.5% gelatin solution for 24hrs prior to the experiment
- Trypsinize cells, count (re-suspended in 5ml media) and make up concentration of 50,000 cells per 100ml (times by the amount needed - in this case 1ml)
- Tag cells (500ml) with Invitrogen C34552 cell tracker
- Pipette 100ml of cell/ media mix into eppendorf with material sample and then add 400ml of media to make up to 500ml in total
- Place closed tubes in shaker at 37 °C, at 600rpm, and leave for 2 hours
- After 2 hours remove materials from eppendorf tubes and place in separate wells of a 24 well plate. Add media from tube to cover sample. Incubate for 24hrs and then fix for imaging

FIXING

- Remove media and add 1ml of PFA to each well, leave for 30 mins
- Remove PFA, add 1ml of PBS to each well, and agitate for 10mins, repeat.
- Place each material sample on a glass slide, add 150ml of moviol and add cover slip, leave to set for 24hrs

SEEDING



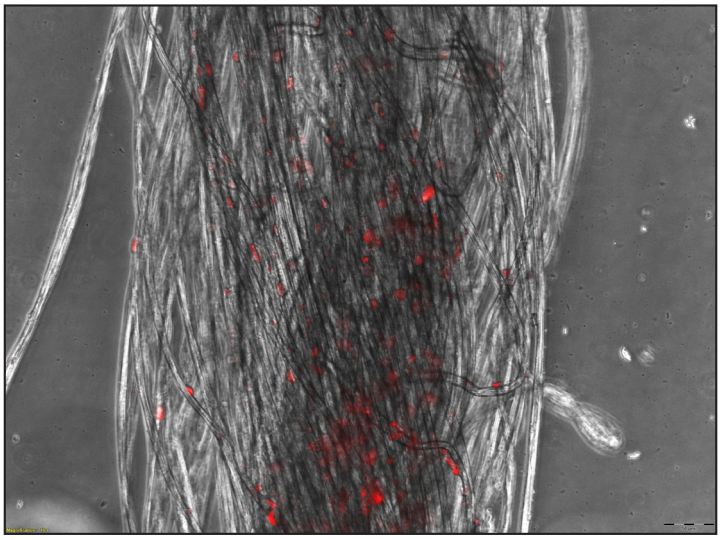
NOTES

- The different material samples were cut to 1cm in length and autoclaved in small glass petri dishes.
- All samples were coated in gelatin prior to seeding to assess if this would improve adherance. The yarns can then be compared to those of experiment 1.
- Only one cell tracker was used, Invitrogen C34552, as it had the least crossover when imaging

Results

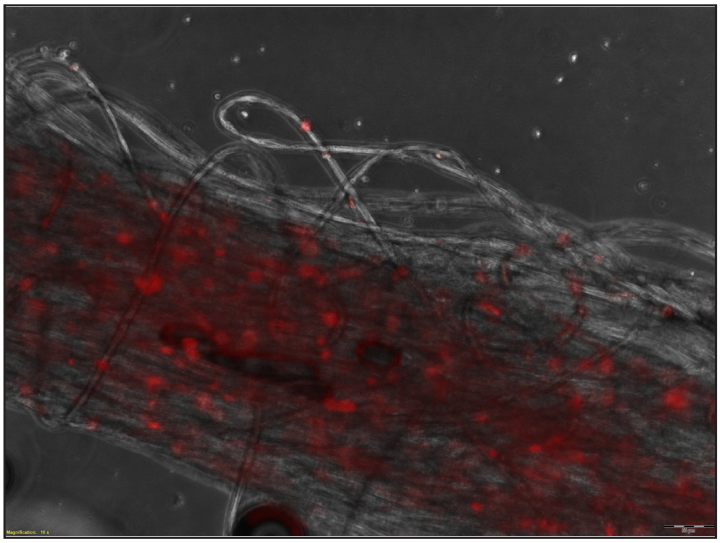
x10 magnification

Brightfield image combined with red & green cell images - composite image 24hrs post seeding



x10 magnification

Brightfield image combined with red & green cell images - composite image 24hrs post seeding



NOTES

- The SeaCell fibre appears to still be very biologically compatible, as in experiment 1 there were the most cells visible on this material.
- There was some indication that the gelatin made the SeaCell even more attractive to the cells, but in both iterations of the experiment there were lots of cells visible under the microscope.

Experiment 3

DATE	19.04.2016
CELL TYPE	HDFBs *(Human dermal fibroblast (skin) cells)*
MEDIA TYPE	K45 Fib GM Media *Made by Promocell*
MATERIALS SEEDED	Milk & SeaCell

AIM

To assess adherence, of a different cell type, on the two most biologically compatible materials

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PROTOCOL

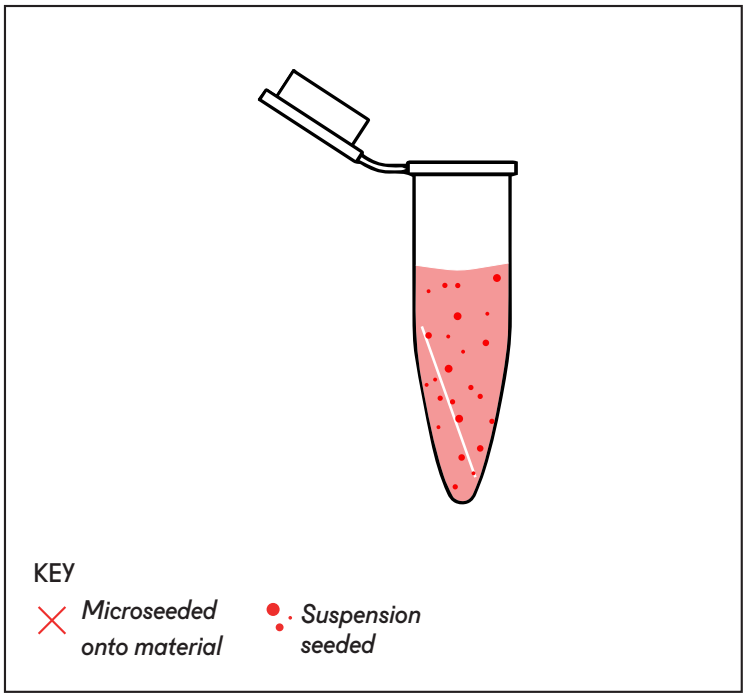
SEEDING

- Grow sufficient number of HDFB cells to be able to seed all materials - for this experiment each material needs 50,000 cells
- Using sterile tweezers transfer autoclaved material samples into separate eppendorf tubes
- Trypsinize cells, count (re-suspended in 5ml media) and make up concentration of 50,000 cells per 100ml (times by the amount needed - in this case 1ml)
- Tag cells with Invitrogen C34552 cell tracker
- Pipette 100ml of cell/ media mix into eppendorf with material sample and then add 400ml of media to make up to 500ml in total
- Place closed tubes in shaker at 37 °C, at 600rpm, and leave for 2 hours
- After 2 hours remove materials from eppendorf tubes and place in separate wells of a 24 well plate. Add media from tube to cover sample. Incubate for 24hrs and then fix for imaging

FIXING

- Remove media and add 1ml of PFA to each well, leave for 30 mins
- Remove PFA, add 1ml of PBS to each well, and agitate for 10mins, repeat.
- Place each material sample on a glass slide, add 150ml of moviol and add cover slip, leave to set for 24hrs

SEEDING



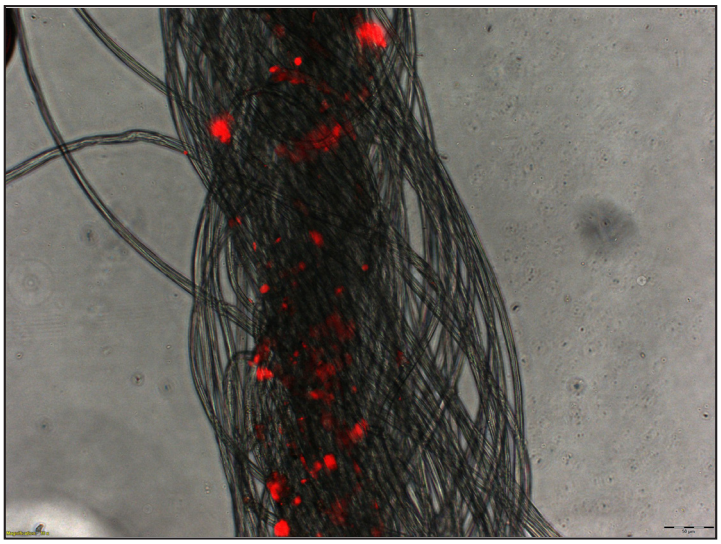
NOTES

- The different material samples were cut to 1cm in length and autoclaved in small glass petri dishes.
- Only one cell tracker was used, Invitrogen C34552, as it had the least crossover when imaging

Results

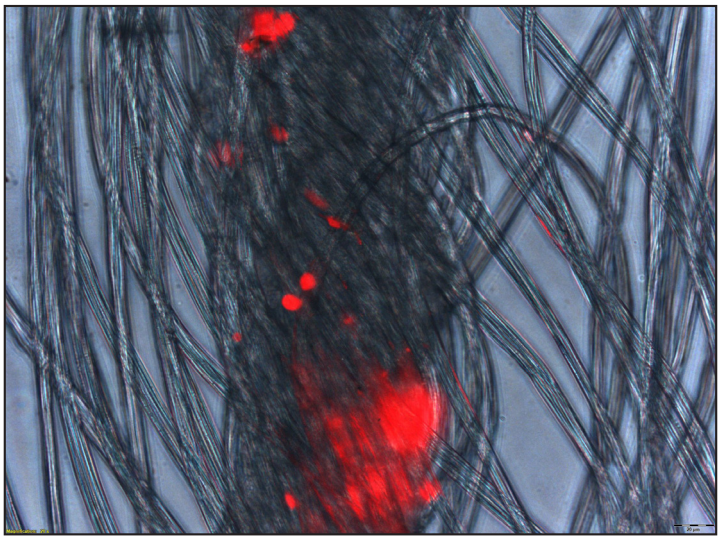
x20 magnification

Brightfield image combined with red cell images - composite image
24hrs post seeding



x20 magnification

Brightfield image combined with red cell images - composite image
24hrs post seeding



NOTES

- Appear to be less cells attached than in previous experiments.
- Cell morphology is rounded, and there are areas where they appear 'clustered' together (see image directly above)
- There were no cells visible on the milk fibre which suggests there may have been an issue whilst seeding
- The previous experiment with HDFB failed due to a problem with cell batch, so this may be having an effect

Experiment 4

DATE	20.04.2016
CELL TYPE	C2C12s *(immortalized mouse myoblast (muscle) cells)*
MEDIA TYPE	DMEM X1 + GlutaMAX *Made by Gibco*
MATERIALS SEEDED	Milk & SeaCell

AIM

To assess adherence, of a different cell type, on the two most biologically compatible materials

---

PROTOCOL

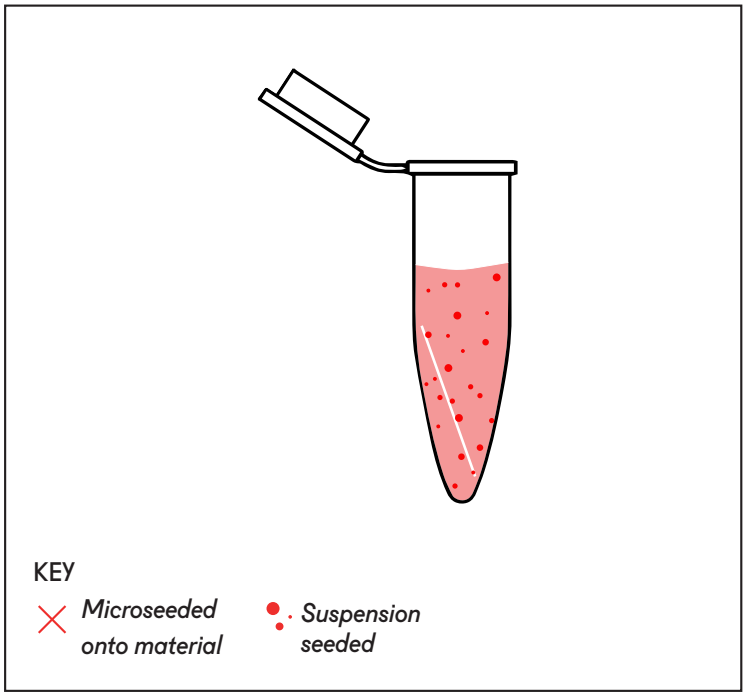
SEEDING

- Grow sufficient number of C2C12 cells to be able to seed all materials - for this experiment each material needs 50,000 cells
- Using sterile tweezers transfer autoclaved material samples into separate eppendorf tubes, the materials were soaked in 0.5% gelatin solution for 24hrs prior to the experiment
- Trypsinize cells, count (re-suspended in 5ml media) and make up concentration of 50,000 cells per 100ml (times by the amount needed - in this case 1ml)
- Tag cells with Invitrogen C34552 cell tracker
- Pipette 100ml of cell/ media mix into eppendorf with material sample and then add 400ml of media to make up to 500ml in total
- Place closed tubes in shaker at 37 °C, at 600rpm, and leave for 2 hours
- After 2 hours remove materials from eppendorf tubes and place in separate wells of a 24 well plate. Add media from tube to cover sample. Incubate for 24hrs and then fix for imaging

FIXING

- Remove media and add 1ml of PFA to each well, leave for 30 mins
- Remove PFA, add 1ml of PBS to each well, and agitate for 10mins, repeat.
- Place each material sample on a glass slide, add 150ml of moviol and add cover slip, leave to set for 24hrs

SEEDING



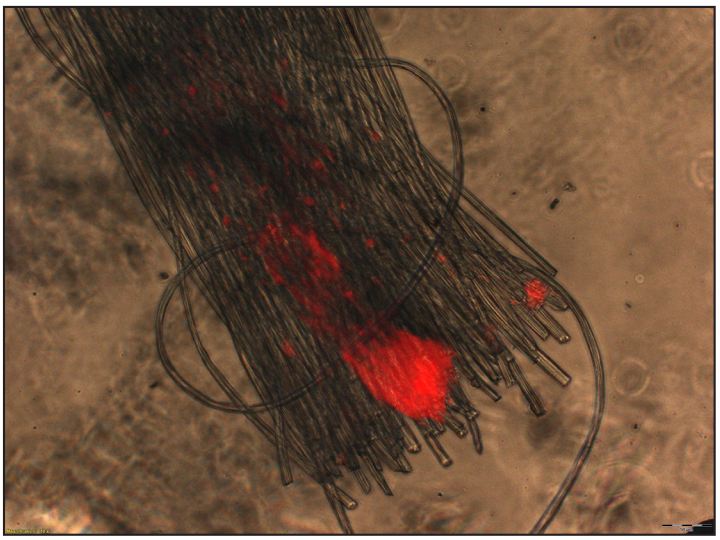
NOTES

- The different material samples were cut to 1cm in length and autoclaved in small glass petri dishes.
- All samples were coated in gelatin prior to seeding to assess if this would improve adherance. The yarns can then be compared to those of experiment 1.
- Only one cell tracker was used, Invitrogen C34552, as it had the least crossover when imaging

Results

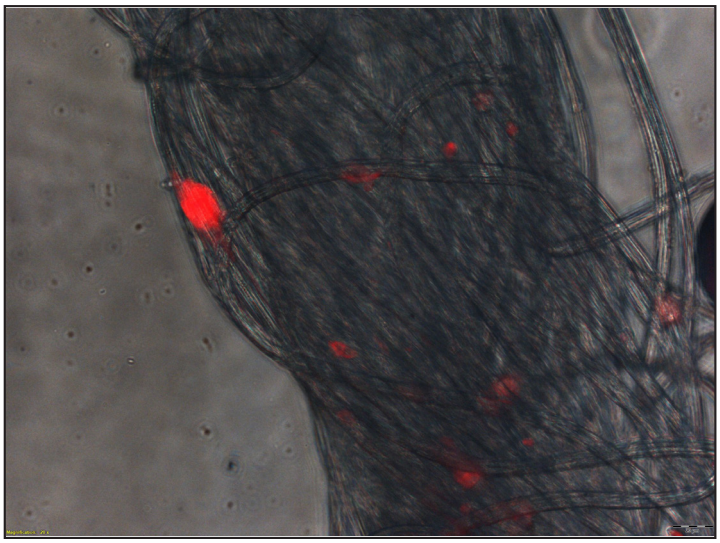
x20 magnification

Brightfield image combined with red cell images - composite image
24hrs post seeding



x20 magnification

Brightfield image combined with red cell images - composite image
24hrs post seeding



NOTES

- Some cells visible
- Morphology is still rounded and not elongated as it should be. However, there is attachment so experiment should be repeated.

Experiment 5

DATE	13.07.2016
CELL TYPE	C2C12s *(immortalized mouse myoblast (muscle) cells)*
MEDIA TYPE	DMEM X1 + GlutaMAX *Made by Gibco*
MATERIALS SEEDED	Milk & SeaCell

AIM

Repeat experiment to assess cell adherence on Milk and SeaCell threads

---

PROTOCOL

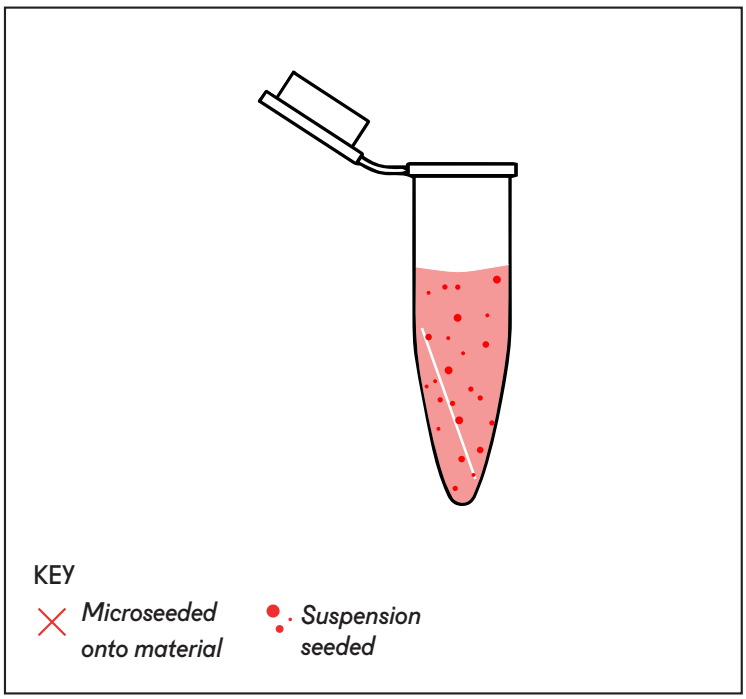
SEEDING

- Grow sufficient number of C2C12 cells to be able to seed all materials - for this experiment each material needs 50,000 cells
- Using sterile tweezers transfer autoclaved material samples into separate eppendorf tubes, the materials were soaked in 0.5% gelatin solution for 24hrs prior to the experiment
- Trypsinize cells, count (re-suspended in 5ml media) and make up concentration of 50,000 cells per 100ml (times by the amount needed - in this case 1ml)
- Pipette 100ml of cell/ media mix into eppendorf with material sample and then add 400ml of media to make up to 500ml in total
- Place closed tubes in shaker at 37 °C, at 600rpm, and leave for 2 hours
- After 2 hours remove materials from eppendorf tubes and place in separate wells of a 24 well plate. Add media from tube to cover sample. Incubate for 24hrs and then fix for imaging

FIXING

- Remove media and add 1ml of PFA to each well, leave for 30 mins
- Remove PFA, add 1ml of PBS to each well, and agitate for 10mins, repeat.
- Add 1µL of phaloid stain to 1ml of PBS - add to each well, cover in foil and shake for 30 mins
- Place each material sample on a glass slide, add 150ml of moviol and add cover slip, leave to set for 24hrs

SEEDING



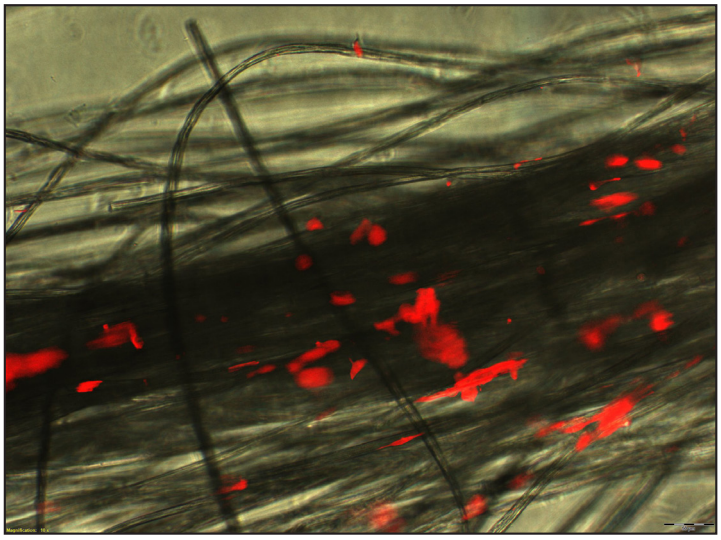
NOTES

- The different material samples were cut to 1cm in length and autoclaved in small glass petri dishes.
- All samples were coated in gelatin prior to seeding improve cell adherance.
- No cell tracker was used in this experiment, instead the cells were stained post fixing with Phaloid stain.

Results

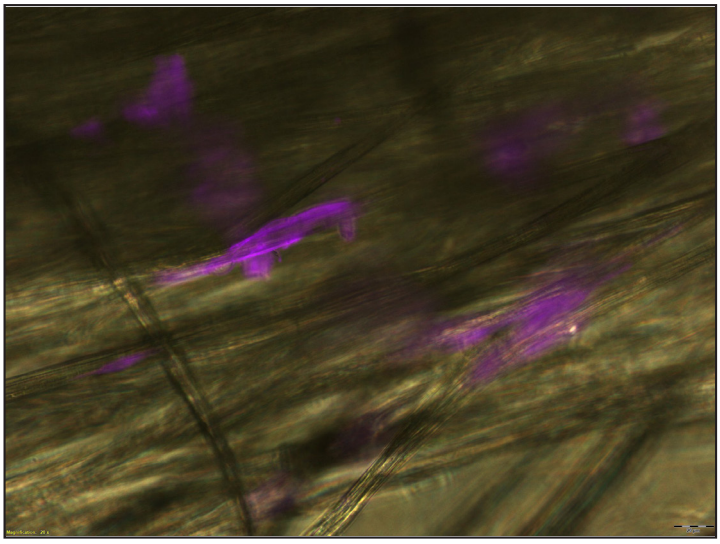
x10 magnification

Brightfield image combined with red cell images - composite image
24hrs post seeding



x20 magnification

Brightfield image combined with purple cell images (different Phaloid stain color used) - composite image
24hrs post seeding



NOTES

- More cells attached in this repeat than in experiment 4.
- Cells have elongated along the individual fibres that make up the thread.

Experiment 6

DATE	19.07.2016
CELL TYPE	C2C12s *(immortalized mouse myoblast (muscle) cells)*
MEDIA TYPE	DMEM X1 + GlutaMAX *Made by Gibco*
MATERIALS SEEDED	SeaCell

AIM

Repeat experiment to assess cell adherence SeaCell thread

PROTOCOL

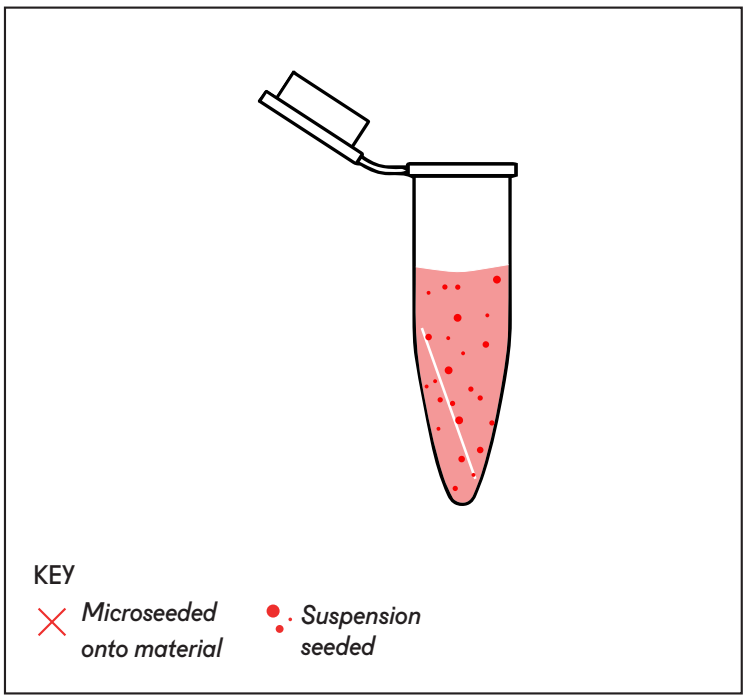
SEEDING

- Grow sufficient number of C2C12 cells to be able to seed all materials - for this experiment each material needs 50,000 cells
- Using sterile tweezers transfer autoclaved material samples into separate eppendorf tubes, the materials were soaked in 0.5% gelatin solution for 24hrs prior to the experiment
- Trypsinize cells, count (re-suspended in 5ml media) and make up concentration of 50,000 cells per 100ml (times by the amount needed - in this case 1ml)
- Pipette 100ml of cell/ media mix into eppendorf with material sample and then add 400ml of media to make up to 500ml in total
- Place closed tubes in shaker at 37 °C, at 600rpm, and leave for 2 hours
- After 2 hours remove materials from eppendorf tubes and place in separate wells of a 24 well plate. Add media from tube to cover sample. Incubate for 24hrs and then fix for imaging

FIXING

- Remove media and add 1ml of PFA to each well, leave for 30 mins
- Remove PFA, add 1ml of PBS to each well, and agitate for 10mins, repeat.
- Add 1µL of phaloid stain to 1ml of PBS - add to each well, cover in foil and shake for 30 mins
- Place each material sample on a glass slide, add 150ml of moviol and add cover slip, leave to set for 24hrs

SEEDING



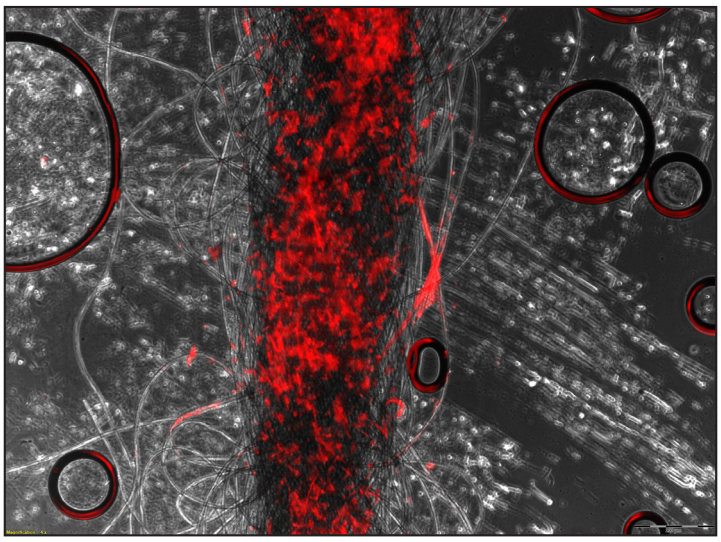
NOTES

- The different material samples were cut to 1cm in length and autoclaved in small glass petri dishes.
- All samples were coated in gelatin prior to seeding improve cell adherance.
- No cell tracker was used in this experiment, instead the cells were stained post fixing with Phaloid stain.

Results

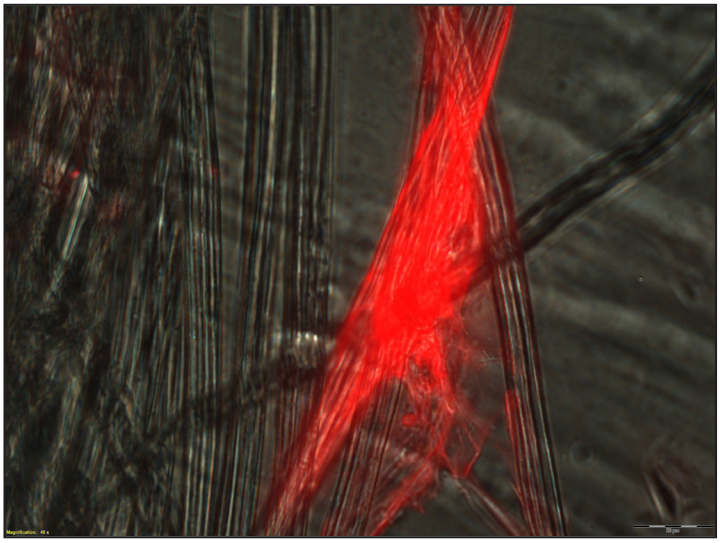
x4 magnification

Brightfield image combined with red cell images - composite image
24hrs post seeding



x40 magnification

Brightfield image combined with red cell images - composite image
24hrs post seeding



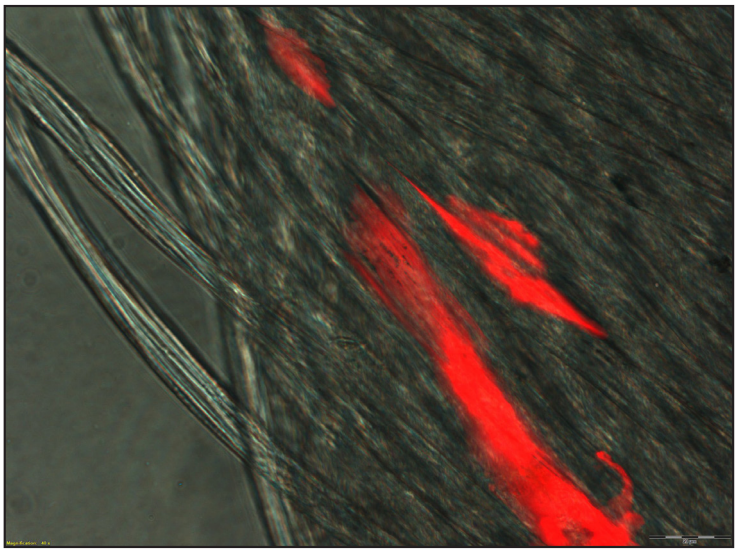
NOTES

- A large number of cells attached to the individual fibres
- Very clear elongation seen along fibres and straddling between - as seen in image above
- For more images see next page

Results

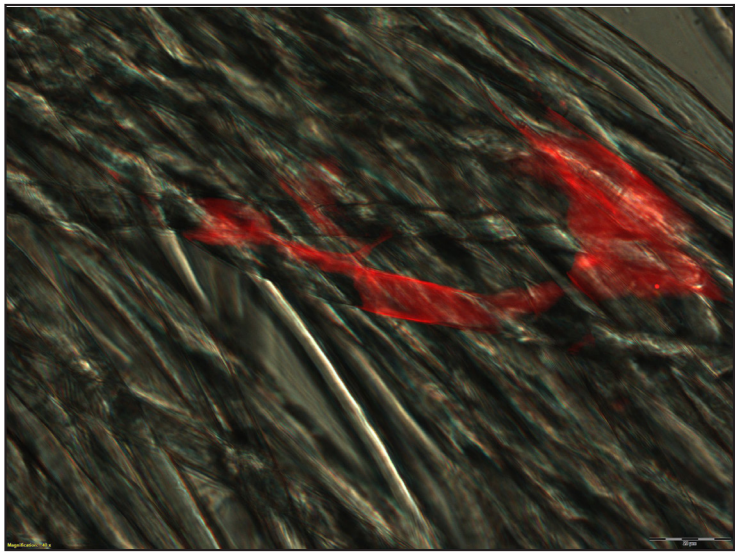
x40 magnification

Brightfield image combined with red cell images - composite image
24hrs post seeding



x40 magnification

Brightfield image combined with red cell images - composite image
24hrs post seeding



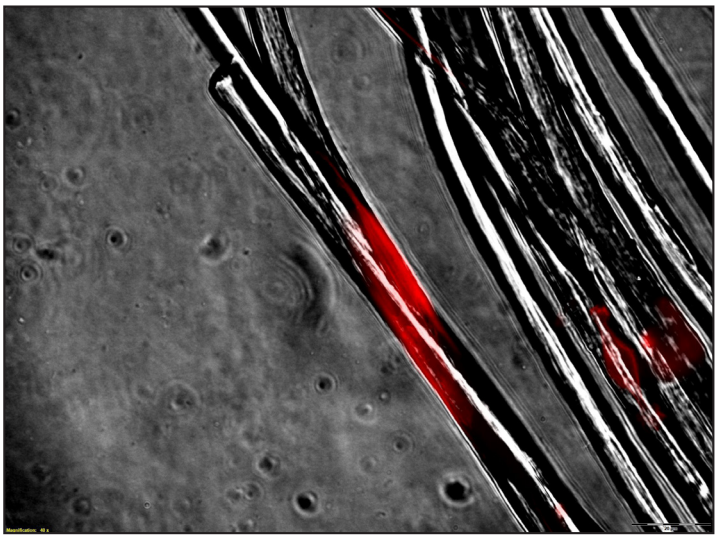
NOTES

- More images of directional cell orientation on fibres
- For more images see next page

Results

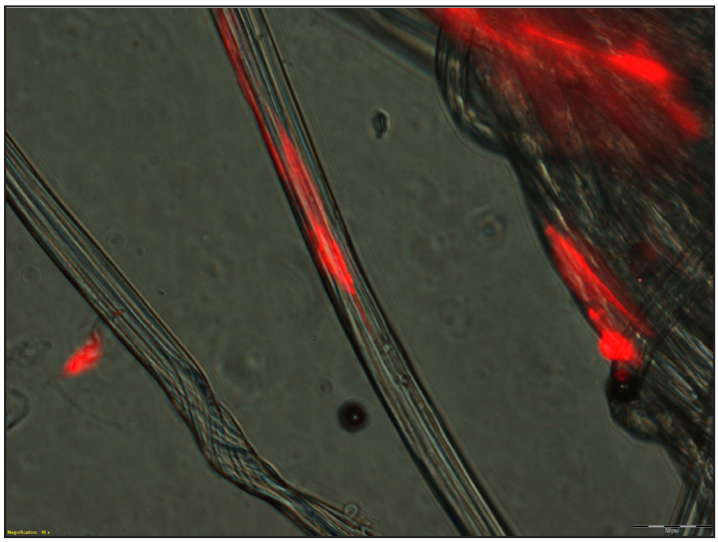
x40 magnification

Brightfield image combined with red cell images - composite image
24hrs post seeding



x40 magnification

Brightfield image combined with red cell images - composite image
24hrs post seeding



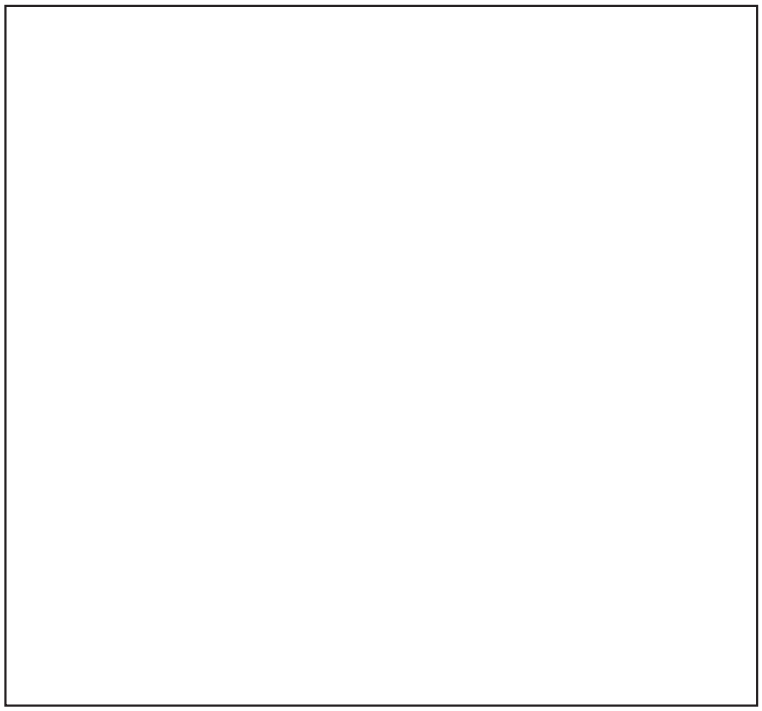
NOTES

- More images of directional cell orientation on fibres
- The diameter of the indivdual fibre appears to be directing the orientation of the cells

Silk & Steel

Silk/ Stainless Steel

MATERIAL SAMPLE



MATERIAL SIZE

200 microns (0.2mm)

MATERIAL STRUCTURE

82/2 nm silk plied with 08/09 A stainless steel

NOTES

- Fabric source: http://handweavers.co.uk/shop/steel_and_copper_blends.html
- Fibre was 'wetable' i.e. absorbs water quickly and does not float, but not as much as many of the others
- Autofluorescence - does not appear to auto-fluoresce in red or green

Experiment 1

DATE	25.01.2016
CELL TYPE	HUVECs *(Human umbilical vein endothelial cells)*
MEDIA TYPE	Endothelial Growth Media 2 (EGM2) *Made by Promocell*
MATERIALS SEEDED	Cotton, Horsehair, Milk, Mohair, Nylon Monofilament, Polyester, SeaCell, Silk, Silk/Steel, Soya

AIM

To assess cell adherence, viability and orientation on a range of 10 different yarns

---

PROTOCOL

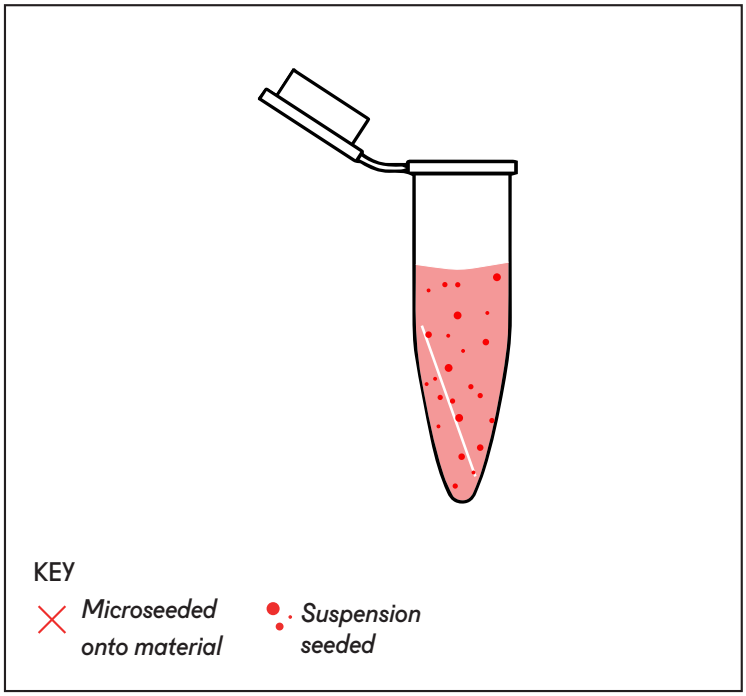
SEEDING

- Grow sufficient number of HUVEC cells to be able to seed all materials - for this experiment each material needs 50,000 cells
- Using sterile tweezers transfer autoclaved material samples into separate eppendorf tubes
- Trypsinize cells, count (re-suspended in 5ml media) and make up concentration of 50,000 cells per 100ml (times by the amount needed - in this case 1ml)
- Tag half of the cells (500ml) with Invitrogen C7025 cell tracker and the other half with Invitrogen C34552 cell tracker and then mix so each scaffold has both colour tracked cells
- Pipette 100ml of cell/ media mix into eppendorf with material sample and then add 400ml of media to make up to 500ml in total
- Place closed tubes in shaker at 37 °C, at 600rpm, and leave for 2 hours
- After 2 hours remove materials from eppendorf tubes and place in separate wells of a 24 well plate. Add media from tube to cover sample. Incubate for 24hrs and then fix for imaging

FIXING

- Remove media and add 1ml of PFA to each well, leave for 30 mins
- Remove PFA, add 1ml of PBS to each well, and agitate for 10mins, repeat.
- Place each material sample on a glass slide, add 150ml of moviol and add cover slip, leave to set for 24hrs

SEEDING



NOTES

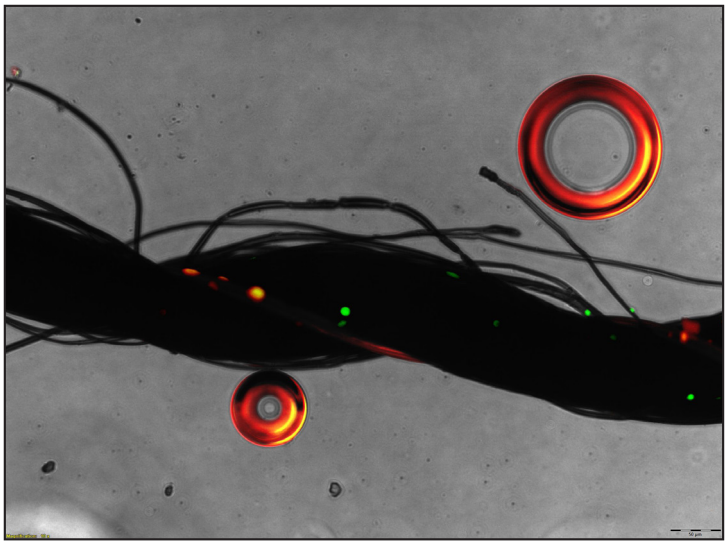
- The different material samples were autoclaved in bags in longer than the required length, they therefore needed cutting down in sterile conditions. This was done by using a sterile petri dish and scalpel blade - cutting approx. 1cm samples of each material and then transferring these to the eppendorf tubes.

- For ease in future experiments it would be better to cut down the material samples to the correct length and autoclave them in a glass petri dish so they are easily found and picked up by tweezers - small samples tend to be lost in autoclave bags and difficult to retrieve

Results

x10 magnification

Brightfield image combined with red & green cell images - composite image 24hrs post seeding



NOTES

- The silk & stainless steel yarn had some cells adhered, but not many.
- During imaging there was crossover in fluorescence between the red and green markers.

Experiment 2

DATE	01.02.2016
CELL TYPE	HUVECs *(Human umbilical vein endothelial cells)*
MEDIA TYPE	Endothelial Growth Media 2 (EGM2) *Made by Promocell*
MATERIALS SEEDED	Cotton, Horsehair, Milk, Mohair, Nylon Monofilament, Polyester, SeaCell, Silk, Silk/Steel, Soya

AIM

To assess cell adherence, viability and orientation on a range of 10 different yarns pre-coated in gelatin

---

PROTOCOL

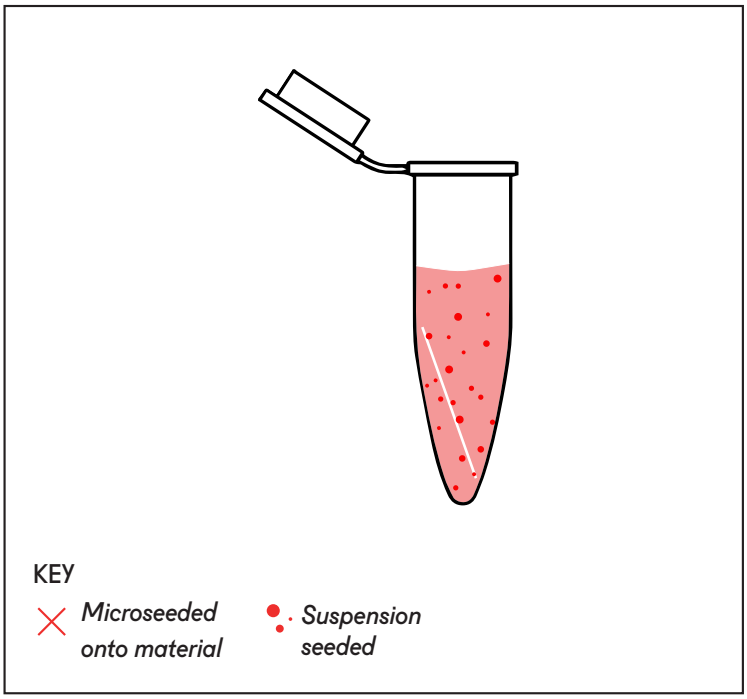
SEEDING

- Grow sufficient number of HUVEC cells to be able to seed all materials - for this experiment each material needs 50,000 cells
- Using sterile tweezers transfer autoclaved material samples into separate eppendorf tubes, the materials were soaked in gelatin for 24hrs prior to the experiment
- Trypsinize cells, count (re-suspended in 5ml media) and make up concentration of 50,000 cells per 100ml (times by the amount needed - in this case 1ml)
- Tag cells with Invitrogen C34552 cell tracker
- Pipette 100ml of cell/ media mix into eppendorf with material sample and then add 400ml of media to make up to 500ml in total
- Place closed tubes in shaker at 37 °C, at 600rpm, and leave for 2 hours
- After 2 hours remove materials from eppendorf tubes and place in separate wells of a 24 well plate. Add media from tube to cover sample. Incubate for 24hrs and then fix for imaging

*F*IXING

- Remove media and add 1ml of PFA to each well, leave for 30 mins
- Remove PFA, add 1ml of PBS to each well, and agitate for 10mins, repeat.
- Cells were also Hoechst stained to mark cell nuclei
- Place each material sample on a glass slide, add 150ml of moviol and add cover slip, leave to set for 24hrs

SEEDING



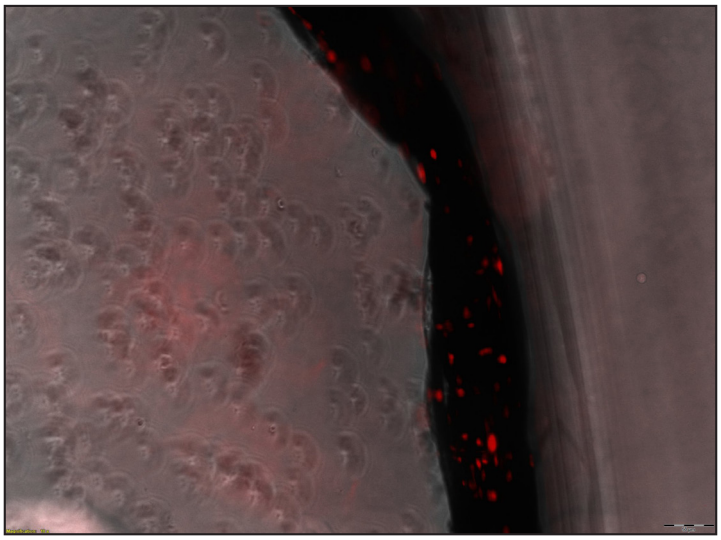
NOTES

- The different material samples were cut to 1cm in length and autoclaved in small glass petri dishes.
- All samples were coated in gelatin prior to seeding to assess if this would improve adherance. The yarns can then be compared to those of experiment 1.
- Only one cell tracker was used, Invitrogen C34552, as it had the least crossover when imaging

Results

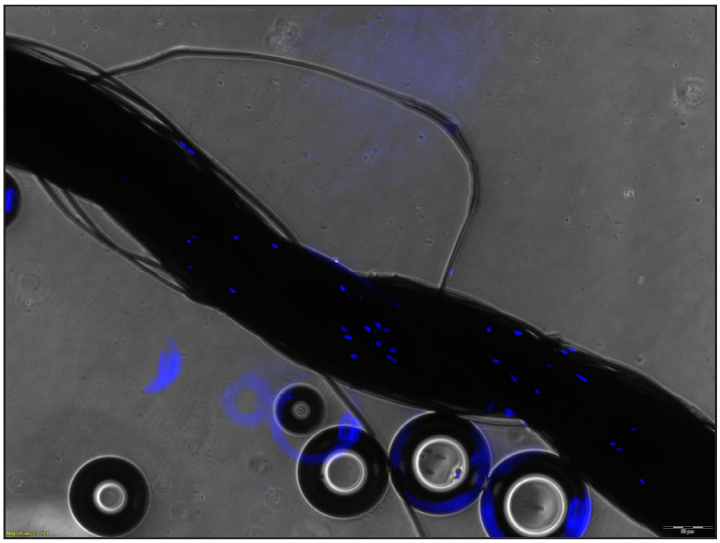
x10 magnification

Brightfield image combined with hoechst stained cell images - composite image
Imaged directly post seeding



x10 magnification

Brightfield image combined with hoechst stained cell images - composite image (same view as above)
24hrs post seeding



NOTES

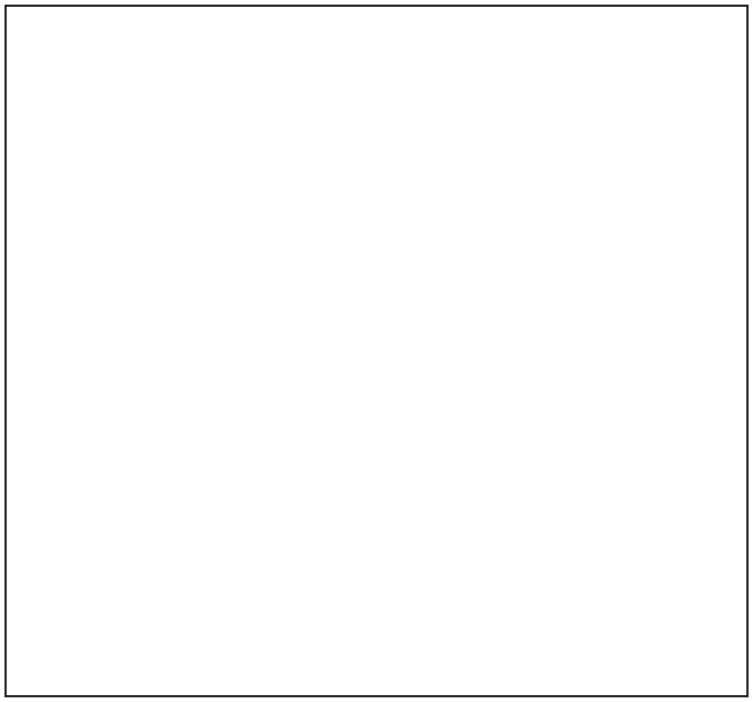
- It appeared that the gelatin made the silk & stainless steel more attractive to the cells, with the coated sample the cells seemed to migrate into the twists of the yarn. However it was difficult to tell if there were the same number as when seeded.

- There appeared to be correlation between cell tracker and the hoechst stain

Silk Suture

Silk Suture

MATERIAL SAMPLE



MATERIAL SIZE

340 microns (0.34mm)

MATERIAL STRUCTURE

Core with 16 strand braid, silicone coated

NOTES

- Fabric source:
  http://www.pearsalls.co.uk/
- Fibre was 'wetable', in that it didn't float. Slightly more hydrophilic than nylon monofilament, but coating appears to prohibit much absorbtion of media and proteins
- Autofluorescence - fluoresces under green and red

Experiment 1

DATE	25.01.2016
CELL TYPE	HUVECs *(Human umbilical vein endothelial cells)*
MEDIA TYPE	Endothelial Growth Media 2 (EGM2) *Made by Promocell*
MATERIALS SEEDED	Cotton, Horsehair, Milk, Mohair, Nylon Monofilament, Polyester, SeaCell, Silk, Silk/Steel, Soya

AIM

To assess cell adherence, viability and orientation on a range of 10 different yarns

---

PROTOCOL

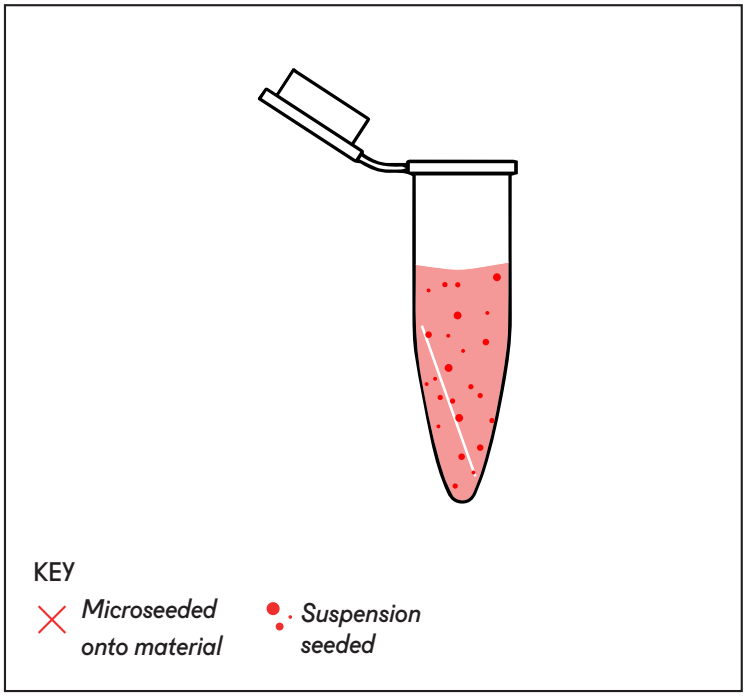
SEEDING

- Grow sufficient number of HUVEC cells to be able to seed all materials - for this experiment each material needs 50,000 cells
- Using sterile tweezers transfer autoclaved material samples into separate eppendorf tubes
- Trypsinize cells, count (re-suspended in 5ml media) and make up concentration of 50,000 cells per 100ml (times by the amount needed - in this case 1ml)
- Tag half of the cells (500ml) with Invitrogen C7025 cell tracker and the other half with Invitrogen C34552 cell tracker and then mix so each scaffold has both colour tracked cells
- Pipette 100ml of cell/ media mix into eppendorf with material sample and then add 400ml of media to make up to 500ml in total
- Place closed tubes in shaker at 37 °C, at 600rpm, and leave for 2 hours
- After 2 hours remove materials from eppendorf tubes and place in separate wells of a 24 well plate. Add media from tube to cover sample. Incubate for 24hrs and then fix for imaging

FIXING

- Remove media and add 1ml of PFA to each well, leave for 30 mins
- Remove PFA, add 1ml of PBS to each well, and agitate for 10mins, repeat.
- Place each material sample on a glass slide, add 150ml of moviol and add cover slip, leave to set for 24hrs

SEEDING



NOTES

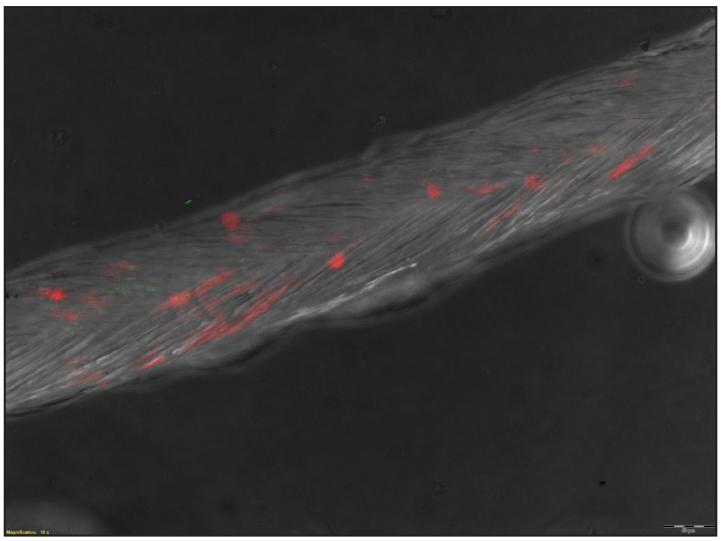
- The different material samples were autoclaved in bags in longer than the required length, they therefore needed cutting down in sterile conditions. This was done by using a sterile petri dish and scalpel blade - cutting approx. 1cm samples of each material and then transferring these to the eppendorf tubes.

- For ease in future experiments it would be better to cut down the material samples to the correct length and autoclave them in a glass petri dish so they are easily found and picked up by tweezers - small samples tend to be lost in autoclave bags and difficult to retrieve

Results

x10 magnification

Brightfield image combined with red & green cell images - composite image 24hrs post seeding



NOTES

- Some cells adhered to thread
- A few appear to have elongated along the outer structure of the braided thread.

Experiment 2

DATE	01.02.2016
CELL TYPE	HUVECs *(Human umbilical vein endothelial cells)*
MEDIA TYPE	Endothelial Growth Media 2 (EGM2) *Made by Promocell*
MATERIALS SEEDED	Cotton, Horsehair, Milk, Mohair, Nylon Monofilament, Polyester, SeaCell, Silk, Silk/Steel, Soya

AIM

To assess cell adherence, viability and orientation on a range of 10 different yarns pre-coated in gelatin

---

PROTOCOL

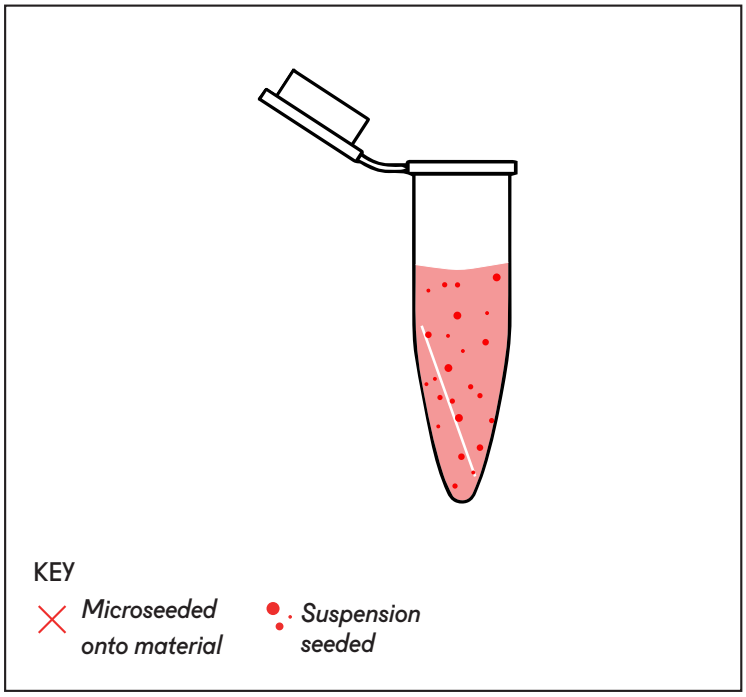
SEEDING

- Grow sufficient number of HUVEC cells to be able to seed all materials - for this experiment each material needs 50,000 cells
- Using sterile tweezers transfer autoclaved material samples into separate eppendorf tubes, the materials were soaked in 0.5% gelatin solution for 24hrs prior to the experiment
- Trypsinize cells, count (re-suspended in 5ml media) and make up concentration of 50,000 cells per 100ml (times by the amount needed - in this case 1ml)
- Tag cells with Invitrogen C34552 cell tracker
- Pipette 100ml of cell/ media mix into eppendorf with material sample and then add 400ml of media to make up to 500ml in total
- Place closed tubes in shaker at 37 °C, at 600rpm, and leave for 2 hours
- After 2 hours remove materials from eppendorf tubes and place in separate wells of a 24 well plate. Add media from tube to cover sample. Incubate for 24hrs and then fix for imaging

*F*IXING

- Remove media and add 1ml of PFA to each well, leave for 30 mins
- Remove PFA, add 1ml of PBS to each well, and agitate for 10mins, repeat.
- Cells were also Hoechst stained to mark cell nuclei
- Place each material sample on a glass slide, add 150ml of moviol and add cover slip, leave to set for 24hrs

SEEDING



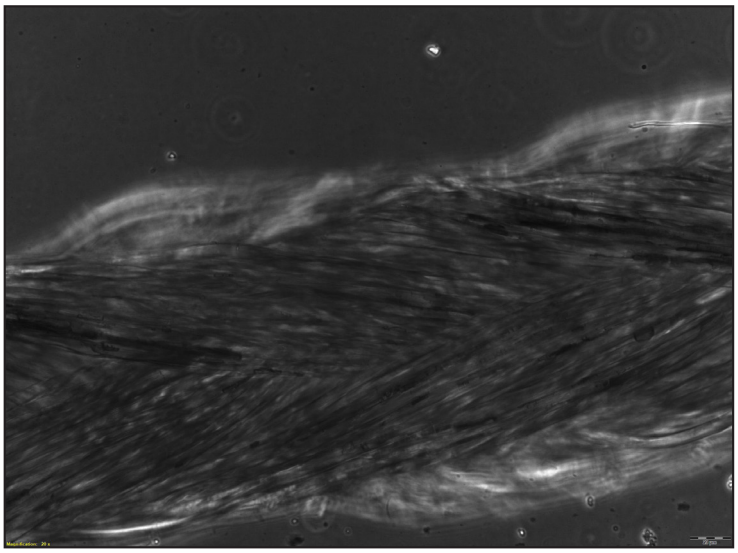
NOTES

- The different material samples were cut to 1cm in length and autoclaved in small glass petri dishes.
- All samples were coated in gelatin prior to seeding to assess if this would improve adherance. The yarns can then be compared to those of experiment 1.
- Only one cell tracker was used, Invitrogen C34552, as it had the least crossover when imaging

Results

x20 magnification

Brightfield image combined with red cell images - composite image
24hrs post seeding



NOTES

- No cells visible

Soya

Soya

MATERIAL SAMPLE

MATERIAL SIZE

20µm (single fibre)

MATERIAL STRUCTURE

Hand spun, single ply

NOTES

- Fabric source:
  https://www.handweavers.co.uk/
- Fibre was 'wetable'
- Autofluorescence - material auto-fluoresced in both green and red

Experiment 1

DATE	25.01.2016
CELL TYPE	HUVECs *(Human umbilical vein endothelial cells)*
MEDIA TYPE	Endothelial Growth Media 2 (EGM2) *Made by Promocell*
MATERIALS SEEDED	Cotton, Horsehair, Milk, Mohair, Nylon Monofilament, Polyester, SeaCell, Silk, Silk/Steel, Soya

AIM

To assess cell adherence, viability and orientation on a range of 10 different yarns

---

PROTOCOL

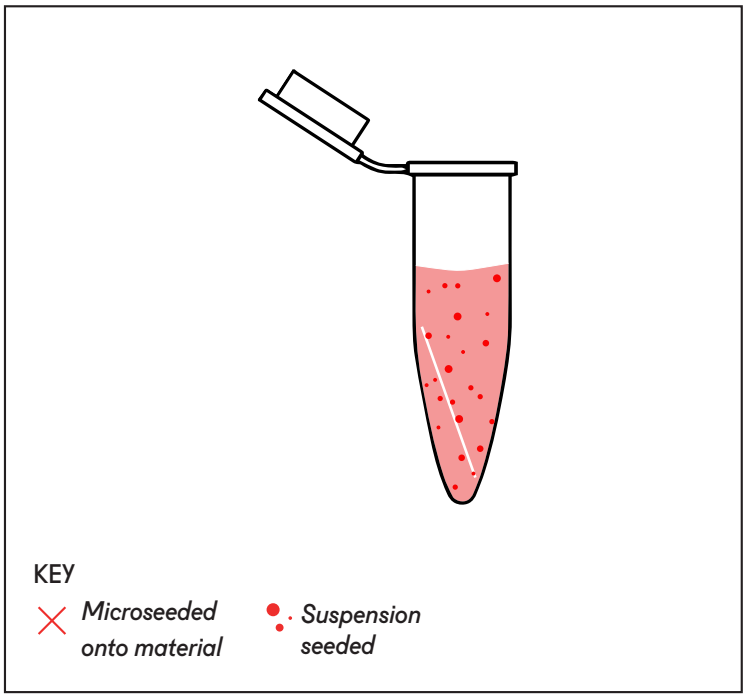
SEEDING

- Grow sufficient number of HUVEC cells to be able to seed all materials - for this experiment each material needs 50,000 cells
- Using sterile tweezers transfer autoclaved material samples into separate eppendorf tubes
- Trypsinize cells, count (re-suspended in 5ml media) and make up concentration of 50,000 cells per 100ml (times by the amount needed - in this case 1ml)
- Tag half of the cells (500ml) with Invitrogen C7025 cell tracker and the other half with Invitrogen C34552 cell tracker and then mix so each scaffold has both colour tracked cells
- Pipette 100ml of cell/ media mix into eppendorf with material sample and then add 400ml of media to make up to 500ml in total
- Place closed tubes in shaker at 37 °C, at 600rpm, and leave for 2 hours
- After 2 hours remove materials from eppendorf tubes and place in separate wells of a 24 well plate. Add media from tube to cover sample. Incubate for 24hrs and then fix for imaging

FIXING

- Remove media and add 1ml of PFA to each well, leave for 30 mins
- Remove PFA, add 1ml of PBS to each well, and agitate for 10mins, repeat.
- Place each material sample on a glass slide, add 150ml of moviol and add cover slip, leave to set for 24hrs

SEEDING



NOTES

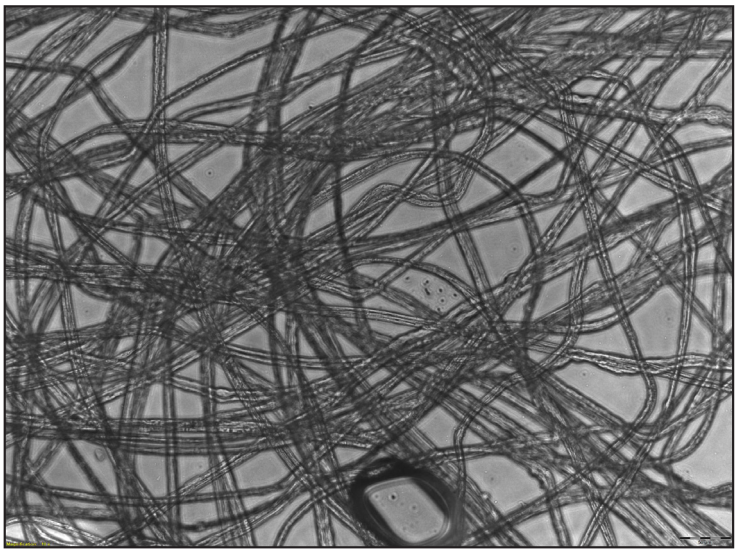
- The different material samples were autoclaved in bags in longer than the required length, they therefore needed cutting down in sterile conditions. This was done by using a sterile petri dish and scalpel blade - cutting approx. 1cm samples of each material and then transferring these to the eppendorf tubes.
- For ease in future experiments it would be better to cut down the material samples to the correct length, autoclave them in a glass petri dish so they are easily found and picked up by tweezers - small samples get lost in autoclave bags and difficult to retrieve
- During autoclaving the Soya fibres became 'crinkled' in appearance after sterilisation

Results

x10 magnification

Brightfield image - no cells seen under green or red fluorescence

24hrs post seeding



NOTES

- No cells visible

Experiment 2

DATE	01.02.2016
CELL TYPE	HUVECs *(Human umbilical vein endothelial cells)*
MEDIA TYPE	Endothelial Growth Media 2 (EGM2) *Made by Promocell*
MATERIALS SEEDED	Cotton, Horsehair, Milk, Mohair, Nylon Monofilament, Polyester, SeaCell, Silk, Silk/Steel, Soya

AIM

To assess cell adherence, viability and orientation on a range of 10 different yarns pre-coated in gelatin

---

PROTOCOL

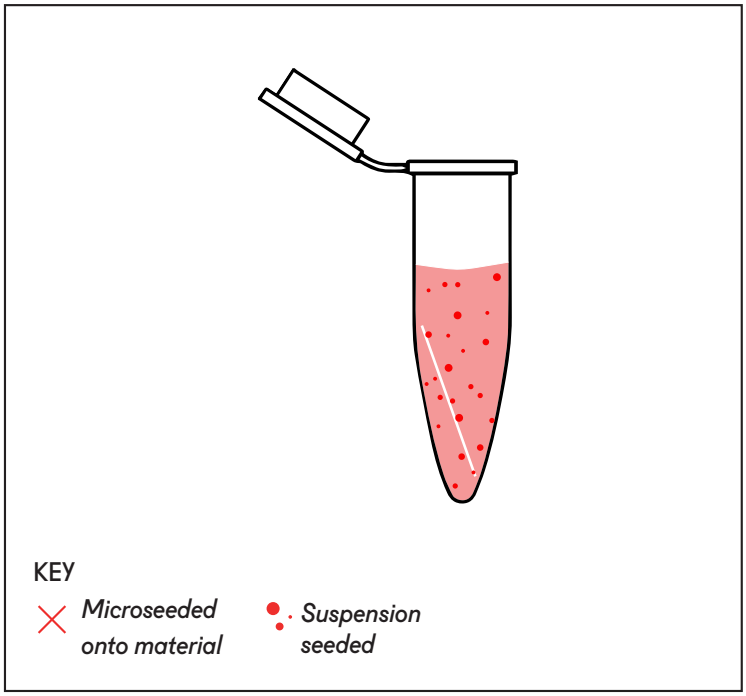
SEEDING

- Grow sufficient number of HUVEC cells to be able to seed all materials - for this experiment each material needs 50,000 cells
- Using sterile tweezers transfer autoclaved material samples into separate eppendorf tubes, the materials were soaked in 0.5% gelatin solution for 24hrs prior to the experiment
- Trypsinize cells, count (re-suspended in 5ml media) and make up concentration of 50,000 cells per 100ml (times by the amount needed - in this case 1ml)
- Tag cells with Invitrogen C34552 cell tracker
- Pipette 100ml of cell/ media mix into eppendorf with material sample and then add 400ml of media to make up to 500ml in total
- Place closed tubes in shaker at 37 °C, at 600rpm, and leave for 2 hours
- After 2 hours remove materials from eppendorf tubes and place in separate wells of a 24 well plate. Add media from tube to cover sample. Incubate for 24hrs and then fix for imaging

*F*IXING

- Remove media and add 1ml of PFA to each well, leave for 30 mins
- Remove PFA, add 1ml of PBS to each well, and agitate for 10mins, repeat.
- Cells were also Hoechst stained to mark cell nuclei
- Place each material sample on a glass slide, add 150ml of moviol and add cover slip, leave to set for 24hrs

SEEDING



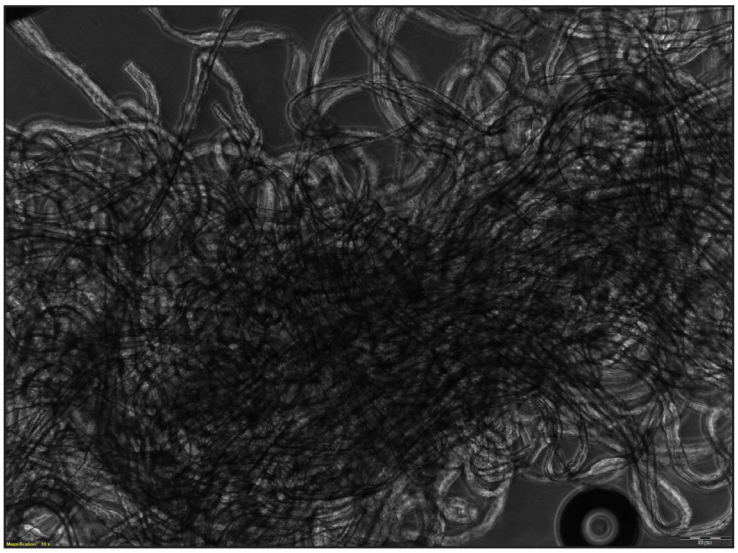
NOTES

- The different material samples were cut to 1cm in length and autoclaved in small glass petri dishes.
- All samples were coated in gelatin prior to seeding to assess if this would improve adherance. The yarns can then be compared to those of experiment 1.
- Only one cell tracker was used, Invitrogen C34552, as it had the least crossover when imaging

Results

x20 magnification

Brightfield image combined with red cell images - composite image
24hrs post seeding



NOTES

- No cells visible

APPENDIX 4

SCAFFOLD WRITE-UPS

Scaffolds Experiment 1

DATE	14.07.2016
CELL TYPE	C2C12s *(immortalized mouse myoblast (muscle) cells)*
MEDIA TYPE	DMEM X1 + GlutaMAX *Made by Gibco*
STRUCTURES SEEDED	Satin stitch and needle punched felt

AIM

To assess cell adherence, viability and orientation on two different textile scaffold structures

---

PROTOCOL

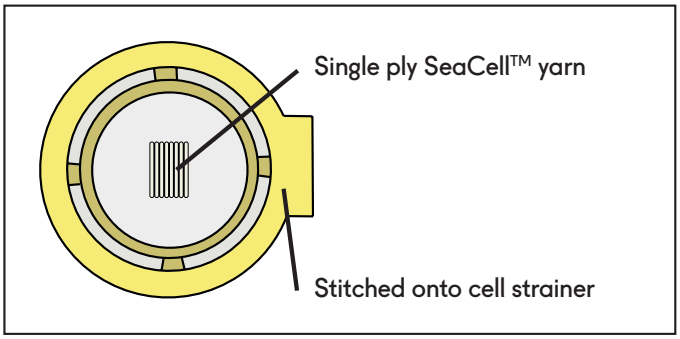
SEEDING

- Grow sufficient number of C2C12 cells to be able to seed all scaffolds - for this experiment each scaffold needs 25,000 cells
- Using sterile tweezers transfer autoclaved scaffolds into separate wells in a 6 well culture plate.
- Cover half of the scaffolds, 3 of each type, with 0.5% gelatin solution and leave for 10 mins. Remove gelatin solution and leave to dry in hood for 30 minutes.
- Trypsinize cells, count and make up concentration of 25,000 cells per 100µl (times by the amount needed - in this case 1.2ml)
- Microseed 100µl of cell/ media mix onto each scaffold, using evenly spaced delivery across the surface.
- Place plates in incubator and leave for 50 mins, then add 1ml extra media per scaffold (carefully to try and minimise cell disruption).
- Place plates in incubator again and leave for a further 50 mins, then add 4ml extra media per scaffold (carefully to try and minimise cell disruption).
- Incubate, and stop at relevant time points - 4 scaffolds at 24hr, 4 scaffolds at 4 days, and final 4 scaffolds at 8 days

*F*IXING

- Remove media and add 3ml of PFA to each well, leave for 30 mins
- Remove PFA, add 3ml of PBS to each well, and agitate for 10mins, repeat.
- Add 3µL of phaloid stain to 3ml of PBS - add to each well, cover in foil and shake for 30 mins

SCAFFOLD DIAGRAM*



SCAFFOLD STRUCTURE

Satin Stitch, single ply SeaCell™

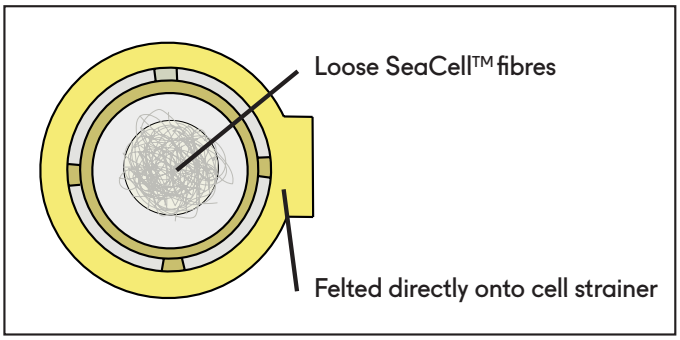
MATERIAL SIZE

320 microns (0.32mm)

NOTES

- Material source: http://handweavers.co.uk/shop/seacell--made-from-seaweed--seacell_top.html#SID=169
- Fibre was the most 'wetable' i.e. absorbs water quickly and does not float
- Autofluorescence - does not appear to auto-fluoresce in red or green

SCAFFOLD DIAGRAM*



SCAFFOLD STRUCTURE

Needle Punched Felt, loose SeaCell™ fibres

MATERIAL SIZE

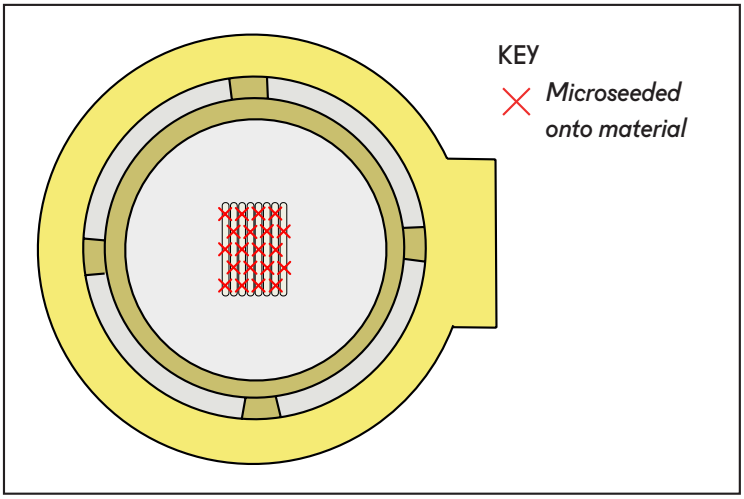
Fibres - 20 microns (0.02mm)

NOTES

- Material source: http://handweavers.co.uk/shop/seacell--made-from-seaweed--seacell_top.html#SID=169
- Fibre was the most 'wetable' i.e. absorbs water quickly and does not float
- Autofluorescence - does not appear to auto-fluoresce in red or green

**not to scale*

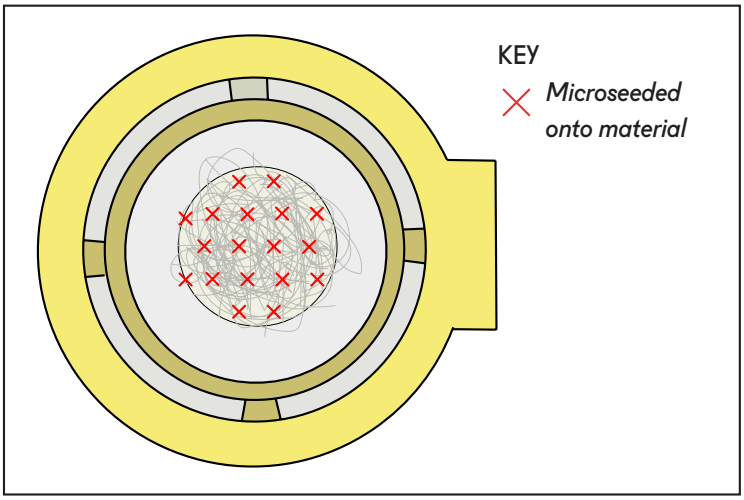
SEEDING



NOTES

- It was difficult to seed as evenly as planned (above) and during the seeding process the scaffolds may have become drier than ideal. Also, it appears 25,000 cells per scaffold is not sufficient (number driven by available cells at time of seeding).

SEEDING



NOTES

- It was difficult to seed as evenly as planned (above) and during the seeding process the scaffolds may have become drier than ideal. Also, it appears 25,000 cells per scaffold is not sufficient (number driven by available cells at time of seeding).

Results - 24 hour

SATIN STITCH

(Problem with microscope - unable to take images)

NOTES

- Some cells attached to threads - rounded in morphology

NEEDLE PUNCHED FELT

(Problem with microscope - unable to take images)

NOTES

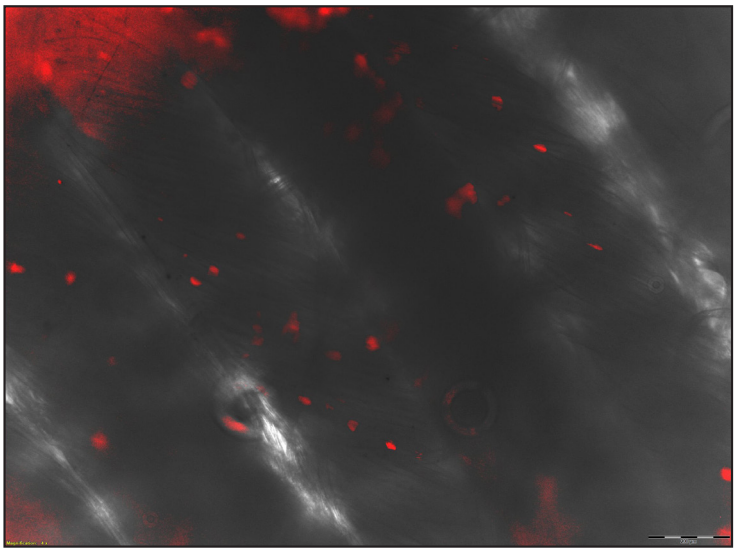
- No cells visible. Unable to tell if this is due to density of felt not allowing light through, that no cells attached, or that the cells died due to being dry

Results - 4 days

SATIN STITCH

x4 magnification

Brightfield image combined with red cell images - composite image



NOTES

- Some cells attached, localised and still rounded

NEEDLE PUNCHED FELT

NOTES

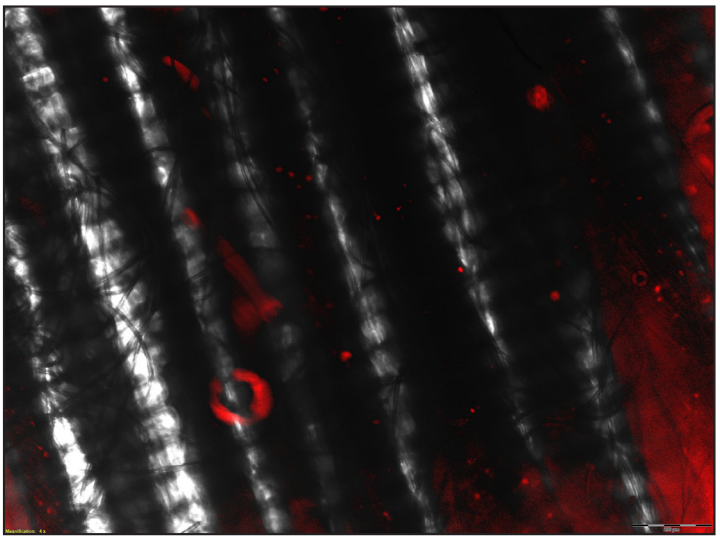
- No cells visible - no further images taken

Results - 8 days

SATIN STITCH

x4 magnification

Brightfield image combined with red cell images - composite image



NOTES

- Some cells attached, localised and still rounded. Did not appear to be any noticeable proliferation of cells.

NEEDLE PUNCHED FELT

NOTES

- No cells visible - no further images taken

Scaffolds Experiment 2

DATE	28.07.2016
CELL TYPE	C2C12s *(immortalized mouse myoblast (muscle) cells)*
MEDIA TYPE	DMEM X1 + GlutaMAX *Made by Gibco*
STRUCTURES SEEDED	Satin stitch, needle punched felt, trapped fibres and couching

AIM

To assess cell adherence, viability and orientation on four different textile scaffold structures

---

PROTOCOL

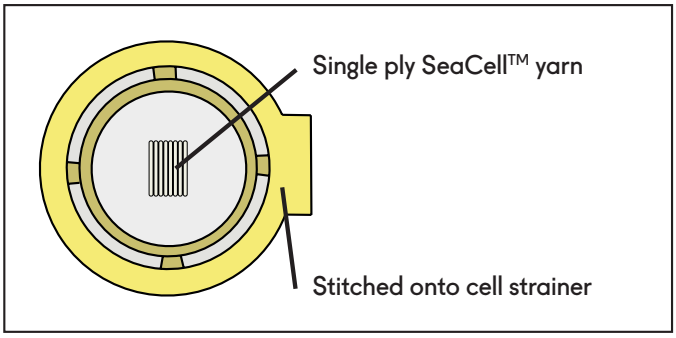
SEEDING

- Grow sufficient number of C2C12 cells to be able to seed all scaffolds - for this experiment each scaffold needs 200,000 cells
- Using sterile tweezers transfer autoclaved scaffolds into separate wells in a 6 well culture plate.
- Cover half of the scaffolds, 3 of each type, with 0.5% gelatin solution and leave for 10 mins. Remove gelatin solution and leave to dry in hood for 30 minutes.
- Trypsinize cells, count and make up concentration of 200,000 cells per 2ml (times by the amount needed - in this case 48ml)
- Flood seed 2ml of cell/ media mix onto each scaffold.
- Place plates in back of hood, rock by hand periodically every 5 minutes for a total of 45 minutes
- Incubate, and stop at relevant time points - 24hr, 5 days, and 8 days

FIXING

- Remove media and add 3ml of PFA to each well, leave for 30 mins
- Remove PFA, add 3ml of PBS to each well, and agitate for 10mins, repeat.
- Add 3µL of phaloid stain to 3ml of PBS - add to each well, cover in foil and shake for 30 mins

SCAFFOLD DIAGRAM*



SCAFFOLD STRUCTURE

Satin Stitch, single ply SeaCell™

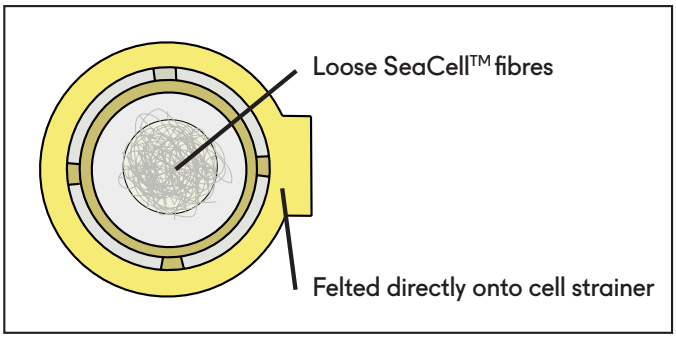
MATERIAL SIZE

320 microns (0.32mm)

NOTES

- Material source: http://handweavers.co.uk/shop/seacell--made-from-seaweed--seacell_top.html#SID=169
- Fibre was the most 'wetable' i.e. absorbs water quickly and does not float
- Autofluorescence - does not appear to auto-fluoresce in red or green

SCAFFOLD DIAGRAM*



SCAFFOLD STRUCTURE

Needle Punched Felt, loose SeaCell™ fibres

MATERIAL SIZE

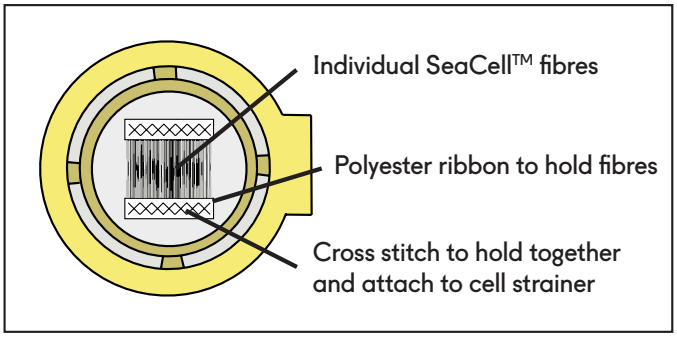
Fibres - 20 microns (0.02mm)

NOTES

- Material source: http://handweavers.co.uk/shop/seacell--made-from-seaweed--seacell_top.html#SID=169
- Fibre was the most 'wetable' i.e. absorbs water quickly and does not float
- Autofluorescence - does not appear to auto-fluoresce in red or green

**not to scale*

SCAFFOLD DIAGRAM*



SCAFFOLD STRUCTURE

Trapped individual SeaCell™ fibres

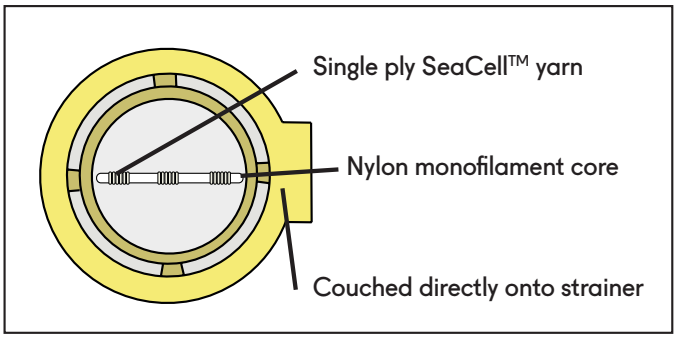
MATERIAL SIZE

Fibres - 20 microns (0.02mm)

NOTES

- Material source: http://handweavers.co.uk/shop/seacell--made-from-seaweed--seacell_top.html#SID=169
- Fibre was the most 'wetable' i.e. absorbs water quickly and does not float
- Autofluorescence - does not appear to auto-fluoresce in red or green

SCAFFOLD DIAGRAM*



SCAFFOLD STRUCTURE

Nylon monofilament couched with single ply SeaCell™ yarn

MATERIAL SIZE

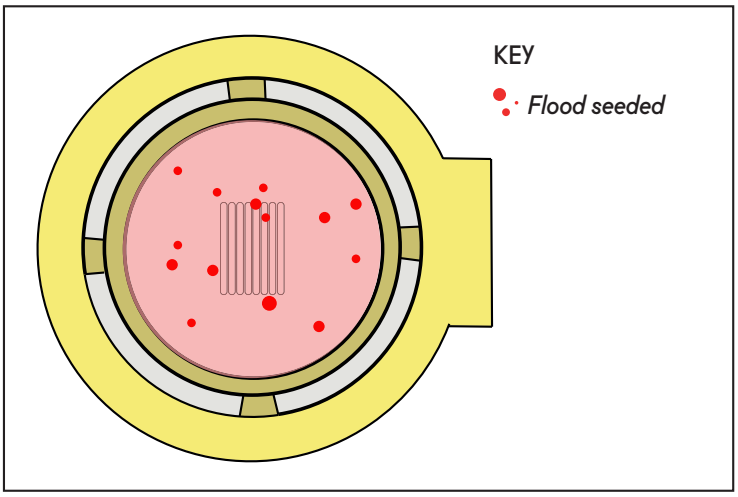
SeaCell™ yarn - 320 microns, nylon filament - 500 microns

NOTES

- Material sources: SeaCell™ as before. Nylon monofilament 'Climax High Quality Filament' http://modelshop.co.uk/
- SeaCell™ as before. Nylon was 'wetable', (didn't float) but it cannot absorb liquid and therefore media and proteins.
- Autofluorescence - SeaCell™ as before. Nylon fluoresced under green, and under red

**not to scale*

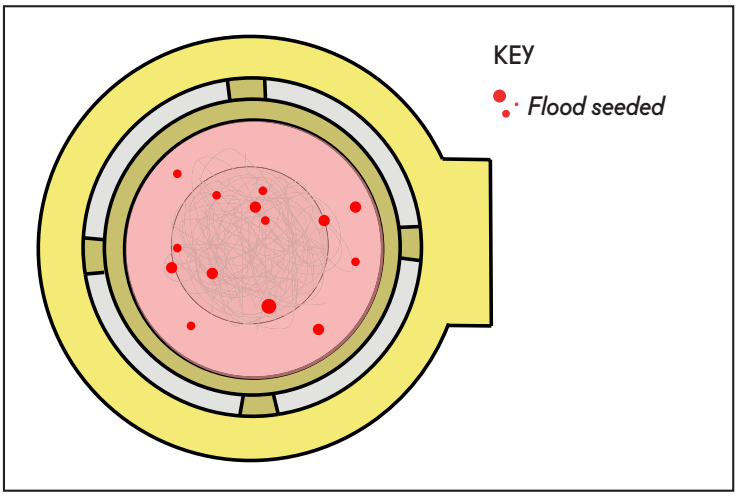
SEEDING



NOTES

- Due to only a few cells being attached in experiment 1 - the seeding method was re-evaluated. Scaffolds were flooded with media containing cells and rocked periodically for 45 minutes. This was also problematic as some scaffolds are thicker than others.

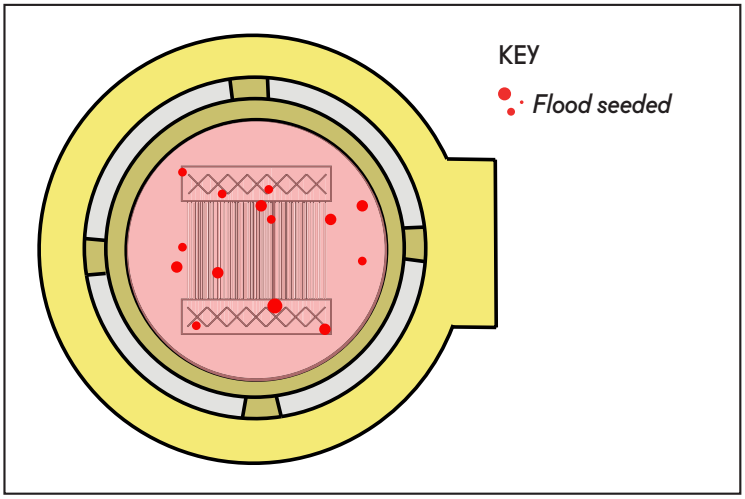
SEEDING



NOTES

- Due to only a few cells being attached in experiment 1 - the seeding method was re-evaluated. Scaffolds were flooded with media containing cells and rocked periodically for 45 minutes. This was also problematic as some scaffolds are thicker than others.

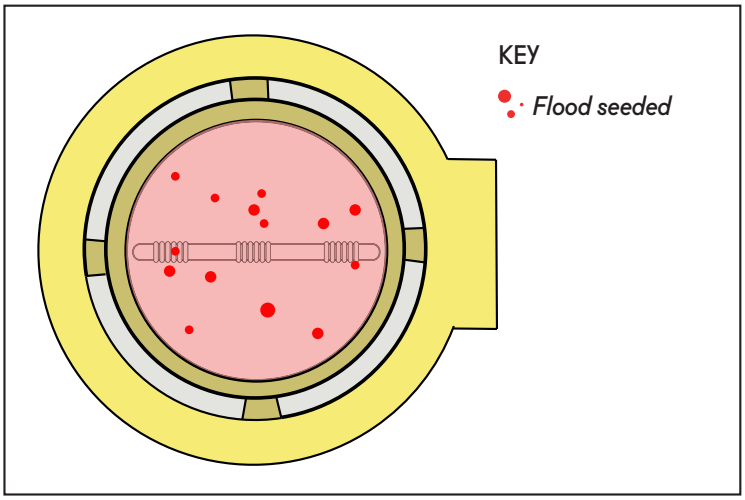
SEEDING



NOTES

- Due to only a few cells being attached in experiment 1 - the seeding method was re-evaluated. Scaffolds were flooded with media containing cells and rocked periodically for 45 minutes. This was also problematic as some scaffolds are thicker than others.

SEEDING



NOTES

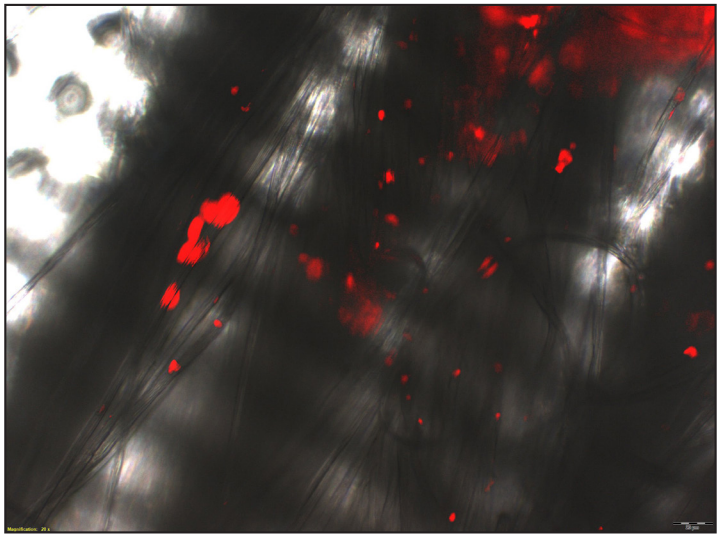
- Due to only a few cells being attached in experiment 1 - the seeding method was re-evaluated. Scaffolds were flooded with media containing cells and rocked periodically for 45 minutes. This was also problematic as some scaffolds are thicker than others.

Results - 24 hour

SATIN STITCH

x20 magnification

Brightfield image combined with red cell images - composite image 24hrs post seeding



NOTES

- Some cells attached, a few orienting along fibre but majority are rounded

NEEDLE PUNCHED FELT

(Unfortunately, as with previous felt scaffold no cells were visible to image)

NOTES

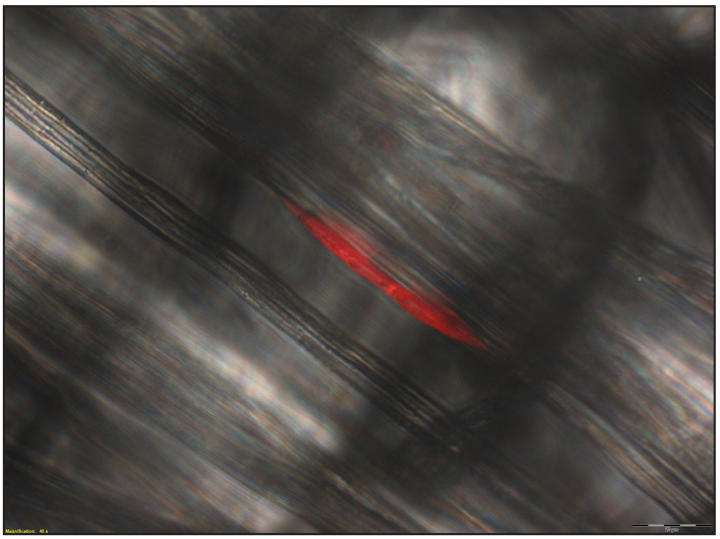
- Re-tried seeding needle felt to see if a less dense scaffold would allow imaging, or if a different seeding method would be more successful.

Results - 24 hour

TRAPPED FIBRES

x40 magnification

Brightfield image combined with red cell images - composite image 24hrs post seeding



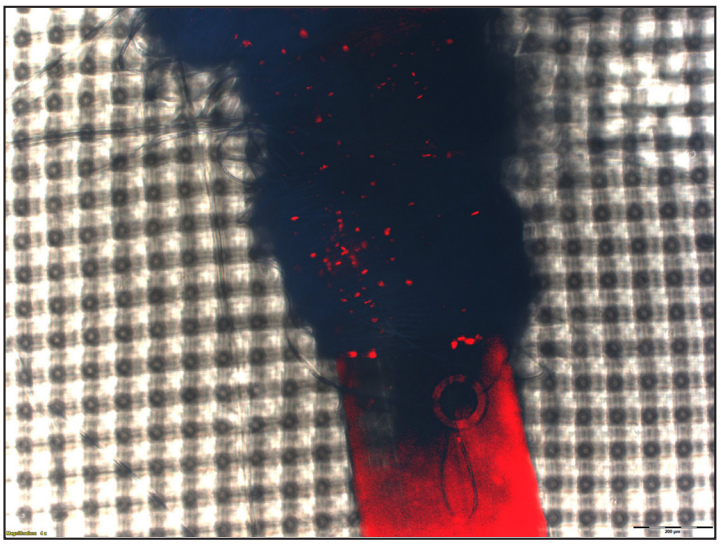
NOTES

- Very few cells attached. Those that are have elongated along the fibres

COUCHED NYLON

x4 magnification

Brightfield image combined with red cell images - composite image 24hrs post seeding



NOTES

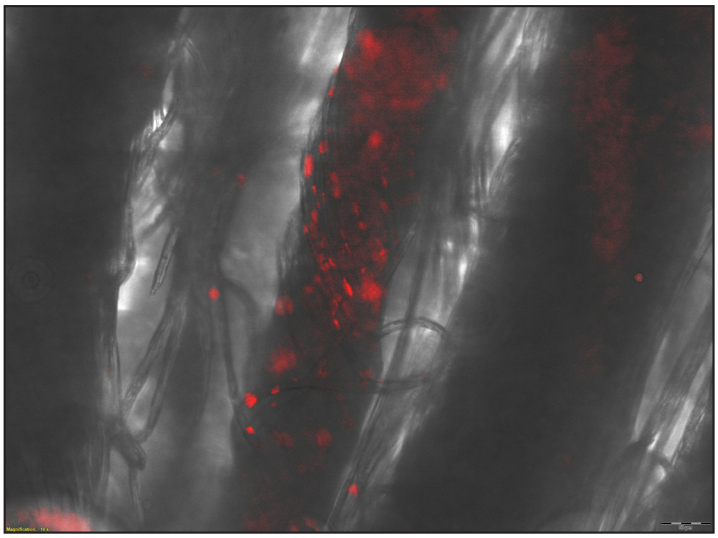
- Cells attached only to the SeaCell™, majority rounded in shape.

Results - 5 days

SATIN STITCH

x10 magnification

Brightfield image combined with red cell images - composite image 24hrs post seeding



NOTES

- Cells locally attached on certain areas of threads. Where grouped they appear to have proliferated

NEEDLE PUNCHED FELT

(Unfortunately, as with previous felt scaffold no cells were visible to image)

NOTES

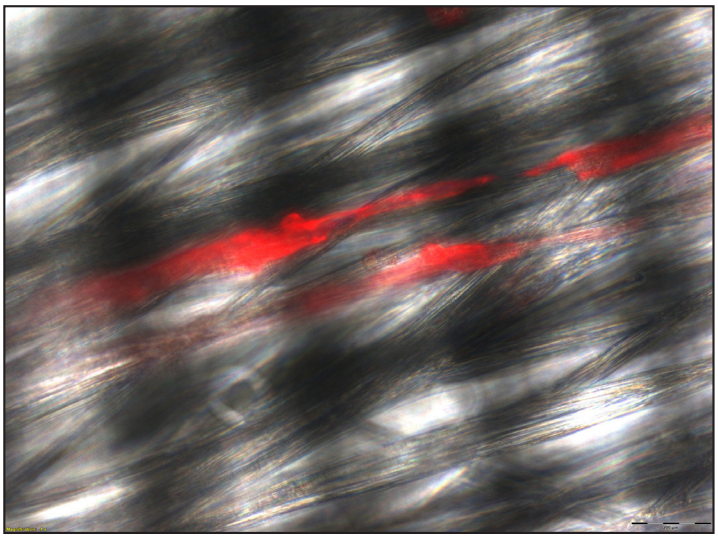
- Re-tried seeding needle felt to see if a less dense scaffold would allow imaging, or if a different seeding method would be more successful.

Results - 5 days

TRAPPED FIBRES

x20 magnification

Brightfield image combined with red cell images - composite image 24hrs post seeding



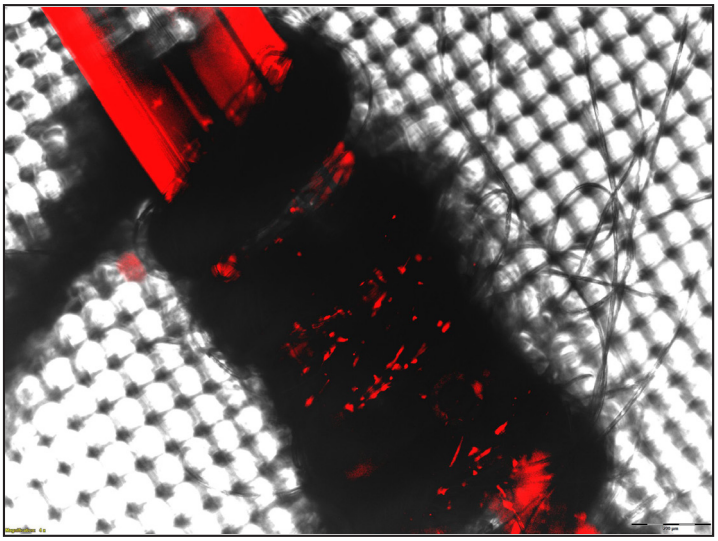
NOTES

- Still very few cells attached. Those that are have elongated along the fibres.

COUCHED NYLON

x4 magnification

Brightfield image combined with red cell images - composite image 24hrs post seeding



NOTES

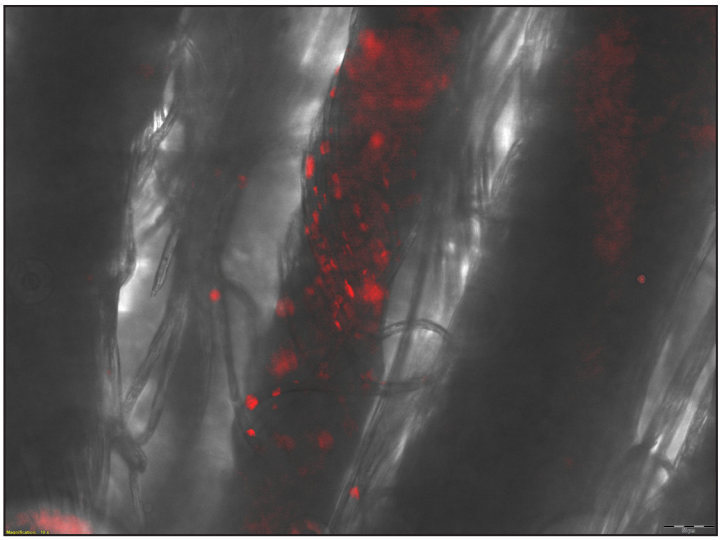
- No cells on the monofilament. Cells appear to have proliferated, elongated and are growing around SeaCell™ fibres.

Results - 8 days

SATIN STITCH

x10 magnification

Brightfield image combined with red cell images - composite image 24hrs post seeding



NOTES

- Same as 5 days - localised cell groups

NEEDLE PUNCHED FELT

(Unfortunately, as with previous felt scaffold no cells were visible to image)

NOTES

- Re-tried seeding needle felt to see if a less dense scaffold would allow imaging, or if a different seeding method would be more successful.

Results - 8 days

TRAPPED FIBRES

x20 magnification

Brightfield image combined with red cell images - composite image 24hrs post seeding

(No image taken due to lack of cells)

NOTES

- Still very few cells - hypothesis is there were too few that attached initially and therefore they did not proliferate well

COUCHED NYLON

x4 magnification

Brightfield image combined with red cell images - composite image 24hrs post seeding

(Image lost due to microscope issue)

NOTES

- No cells on the monofilament and cells growing around SeaCellT™ fibres. Appears to have been some further proliferation

Scaffolds Experiment 3

DATE	2.08.2016
CELL TYPE	C2C12s *(immortalized mouse myoblast (muscle) cells)*
MEDIA TYPE	DMEM X1 + GlutaMAX *Made by Gibco*
STRUCTURES SEEDED	Couched fibres, fibre wrapped monofilament, trapped fibres and macramé

AIM

To assess cell adherence, viability and orientation on four different textile scaffold structures

---

PROTOCOL

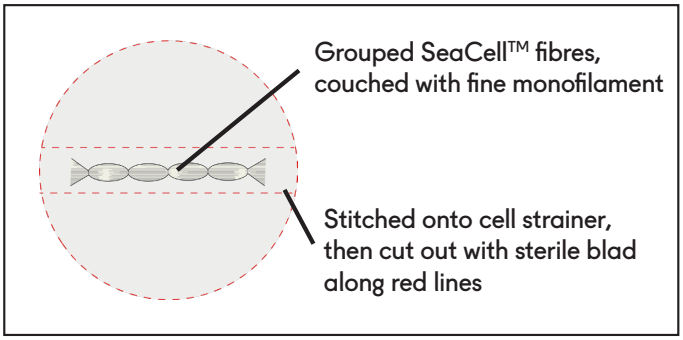
SEEDING

- Grow sufficient number of C2C12 cells to be able to seed all scaffolds - for this experiment each scaffold needs 200,000 cells
- Using a sterile blade cut scaffolds out of cell strainers, cut as close to scaffold as possible, and using sterile tweezers transfer autoclaved scaffolds into separate wells in a 6 well culture plates
- Cover all scaffolds with 0.5% gelatin solution and leave for 10 mins. Remove gelatin solution and leave to dry in hood for 30 minutes.
- Trypsinise cells, count, and then resuspend in the required amount of media - each scaffold should be seeded with 200,000 cells, in 1ml of media.
- Place each individual scaffold into an Eppendorf tube
- Pipette 1ml of media with cells into each of the tubes
- Place tubes in the heated shaker (temp 37°C, speed 600) and leave to shake for 2 hours
- Remove scaffolds from tubes and place in separate wells of a 6 well plate, pipette media from the tube into the well with the material. Add additional media, as needed, if scaffold is not fully covered
- Incubate, and stop at relevant time points - 24hr, 4 days, and 8 days

FIXING

- Remove media and add 3ml of PFA to each well, leave for 30 mins
- Remove PFA, add 3ml of PBS to each well, and agitate for 10mins, repeat.
- Add 3µL of phaloid stain to 3ml of PBS - add to each well, cover in foil and shake for 30 mins

SCAFFOLD DIAGRAM*



SCAFFOLD STRUCTURE

SeaCell™ fibres - Couched w/ nylon monofilament

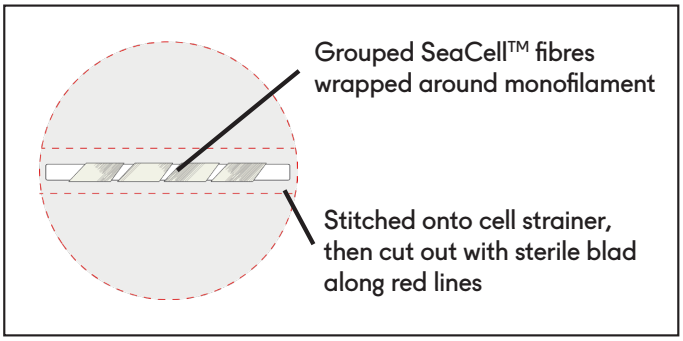
MATERIAL SIZE

SeaCell™ fibres - 20 microns, nylon filament - 150 microns

NOTES

- Material sources:
  SeaCell™ as before. Nylon monofilament 'Climax High Quality Filament' http://modelshop.co.uk/
- SeaCell™ as before. Nylon was 'wetable', (didn't float) but it cannot absorb liquid and therefore media and proteins.
- Autofluorescence - SeaCell™ as before. Nylon fluoresced under green, and under red

SCAFFOLD DIAGRAM*



SCAFFOLD STRUCTURE

Nylon monofilament wrapped with SeaCell™ fibres

MATERIAL SIZE

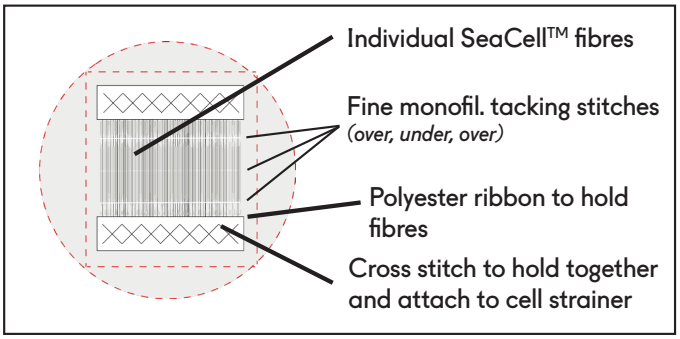
SeaCell™ fibres - 20 microns, nylon filament - 500 microns

NOTES

- Material sources:
  SeaCell™ as before. Nylon monofilament 'Climax High Quality Filament' http://modelshop.co.uk/
- SeaCell™ as before. Nylon was 'wetable', (didn't float) but it cannot absorb liquid and therefore media and proteins.
- Autofluorescence - SeaCell™ as before. Nylon fluoresced under green, and under red

**not to scale*

SCAFFOLD DIAGRAM*



SCAFFOLD STRUCTURE

Trapped SeaCell™ fibres, with tacked monofilament threads

MATERIAL SIZE

SeaCell™ fibres - 20 microns, nylon filament - 150 microns

NOTES

- Material sources:
  SeaCell™ as before. Nylon monofilament 'Climax High Quality Filament' http://modelshop.co.uk/
- SeaCell™ as before. Nylon was 'wetable', (didn't float) but it cannot absorb liquid and therefore media and proteins.
- Autofluorescence - SeaCell™ as before. Nylon fluoresced under green, and under red

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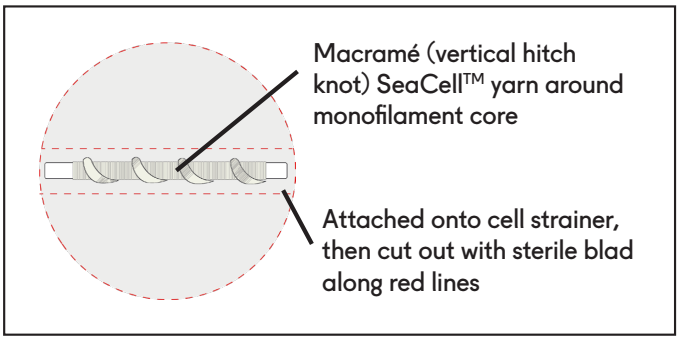
SCAFFOLD DIAGRAM*



SCAFFOLD STRUCTURE

Macramé w/ SeaCell™ thread over nylon monofilament core

MATERIAL SIZE

SeaCell™ yarn - 320 microns, nylon filament - 500 microns

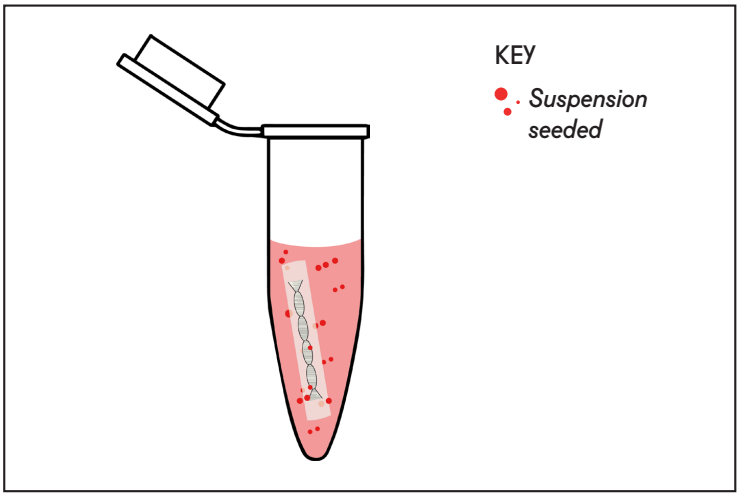
NOTES

- Material sources:
  SeaCell™ as before. Nylon monofilament 'Climax High Quality Filament' http://modelshop.co.uk/
- SeaCell™ as before. Nylon was 'wetable', (didn't float) but it cannot absorb liquid and therefore media and proteins.
- Autofluorescence - SeaCell™ as before. Nylon fluoresced under green, and under red

---

**not to scale*

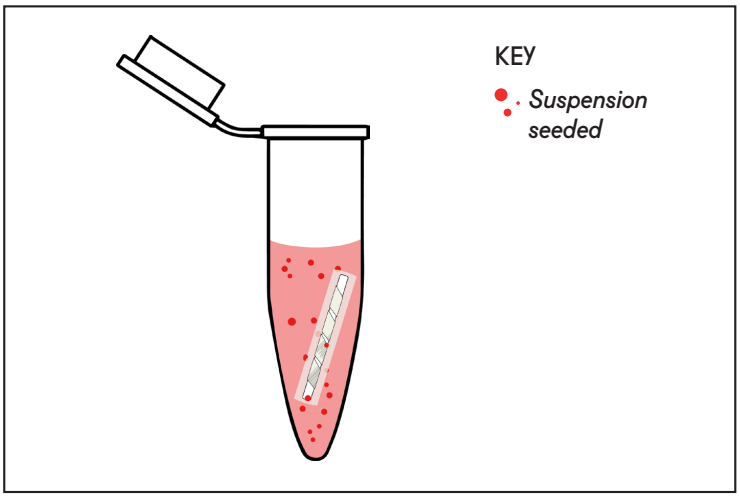
SEEDING



NOTES

- Due to poor results using both microseeding and flood seeding, suspension seeding was used. This involved cutting scaffolds out of the cell strainers and seeding in Eppendorf tubes.

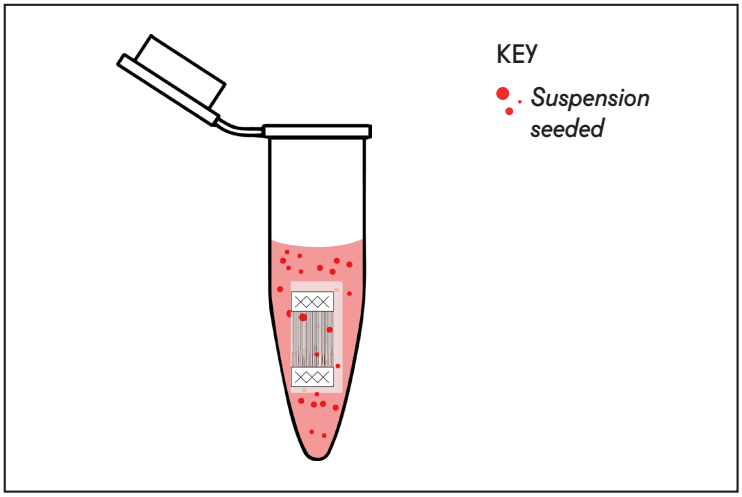
SEEDING



NOTES

- Due to poor results using both microseeding and flood seeding, suspension seeding was used. This involved cutting scaffolds out of the cell strainers and seeding in Eppendorf tubes.

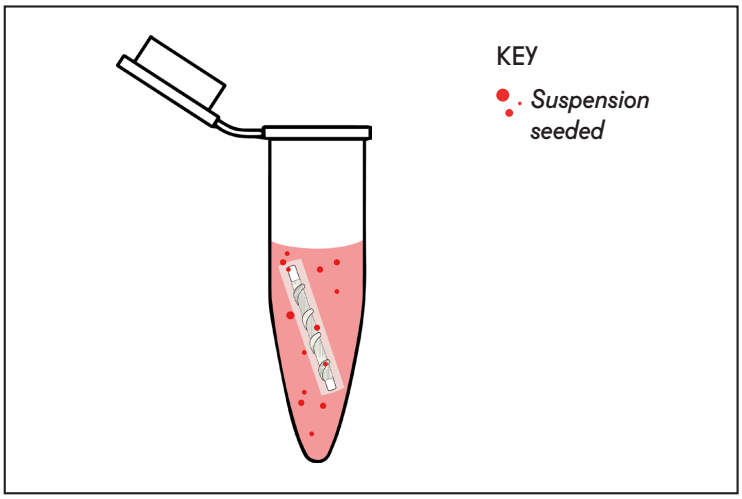
SEEDING



NOTES

- Due to poor results using both microseeding and flood seeding, suspension seeding was used. This involved cutting scaffolds out of the cell strainers and seeding in Eppendorf tubes. This scaffold had to be folded in order to fit in tube.

SEEDING



NOTES

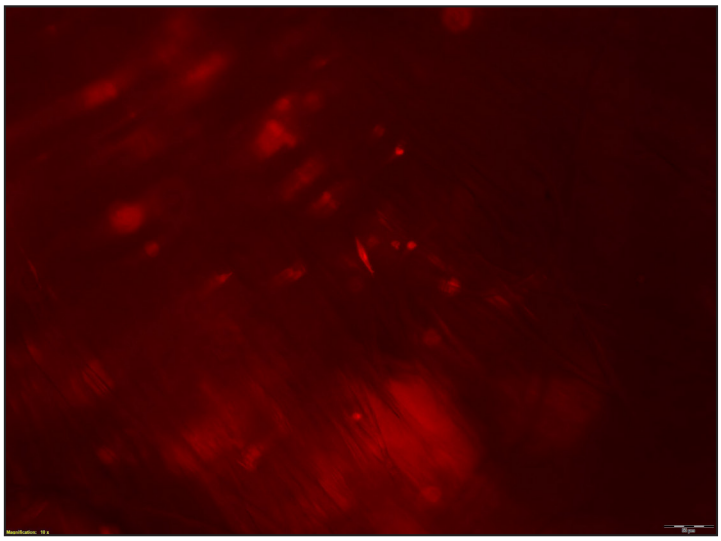
- Due to poor results using both microseeding and flood seeding, suspension seeding was used. This involved cutting scaffolds out of the cell strainers and seeding in Eppendorf tubes.

Results - 24 hour

COUCHED

x10 magnification

Red fluorescent light cell image - 24hr post seeding



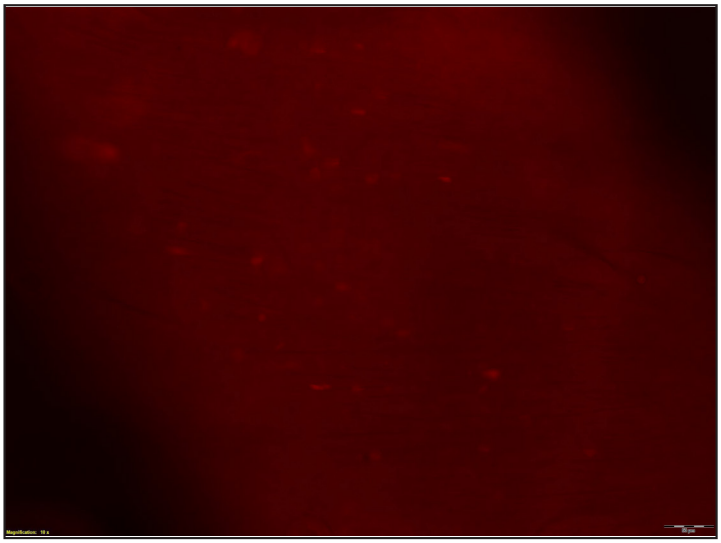
NOTES

- Some cells visible on SeaCell™ fibres - none on monofilament
  (Problem with microscope - only able to take fluorescent images)

WRAPPED

x10 magnification

Red fluorescent light cell image - 24hr post seeding



NOTES

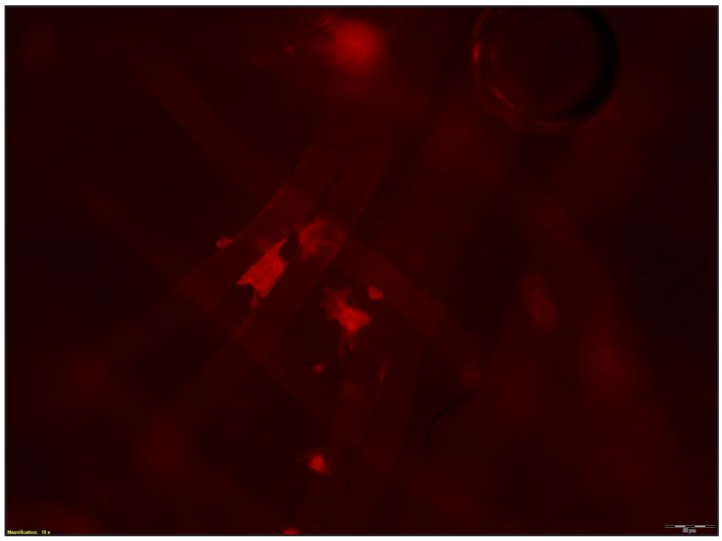
- Some cells, less than couched, visible on SeaCellTM fibres - fairly rounded shape.
  (Problem with microscope - only able to take fluorescent images)

Results - 24 hour

TRAPPED FIBRES

x20 magnification

Red fluorescent light cell image - 24hr post seeding



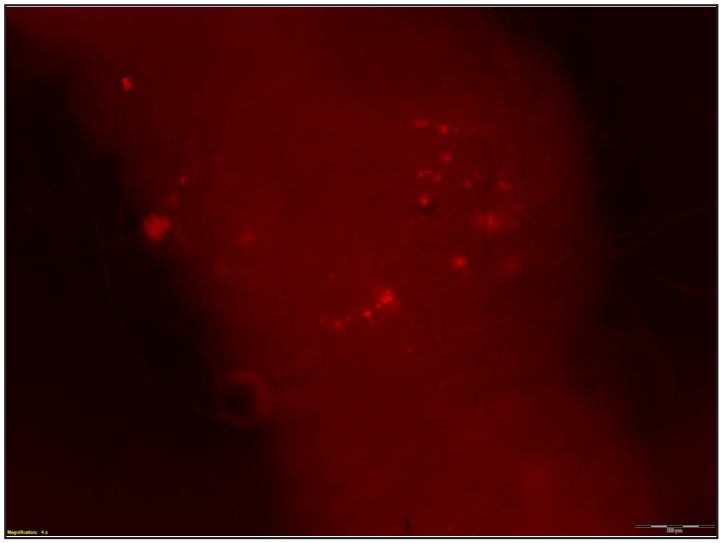
NOTES

- Very few cells visible - a small number attached between individual fibres
  (Problem with microscope - only able to take fluorescent images)

MACRAMÉ

x4 magnification

Red fluorescent light cell image - 24hr post seeding

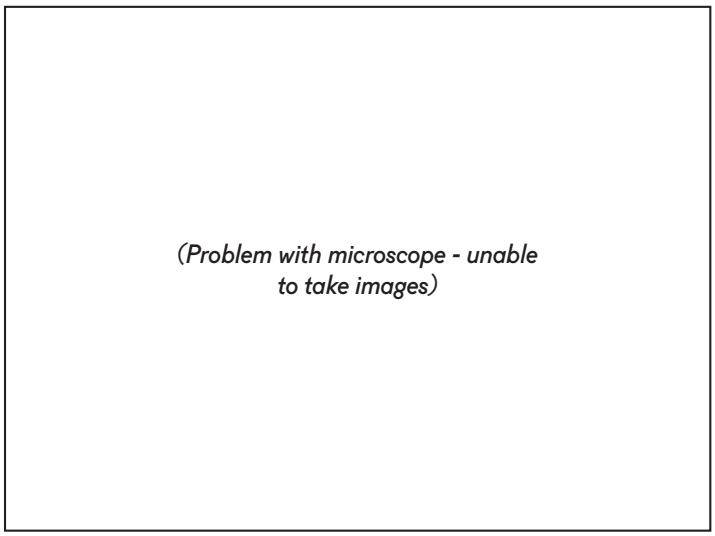


NOTES

- Some cells visible - most concentrated following bottom ridge of macramé
  (Problem with microscope - only able to take fluorescent images)

Results - 4 days

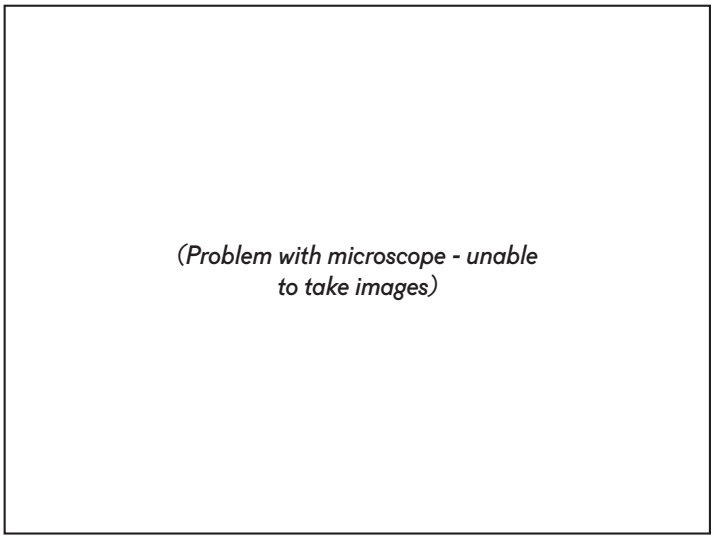
COUCHED



NOTES

- Some cells visible on SeaCell™ - with suggestion of some proliferation

WRAPPED



NOTES

- A number of cells visible - embedded with SeaCell™ fibres

Results - 4 days

TRAPPED FIBRES

(Problem with microscope - unable to take images)

NOTES

- Still very few cells visible

MACRAMÉ

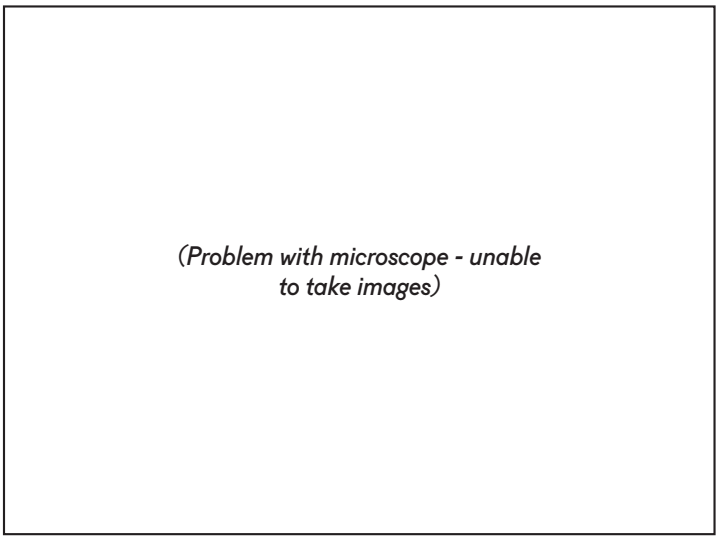
(Problem with microscope - unable to take images)

NOTES

- Cells elongated in places and majority sitting along bottom of ridge in macramé

Results - 8 days

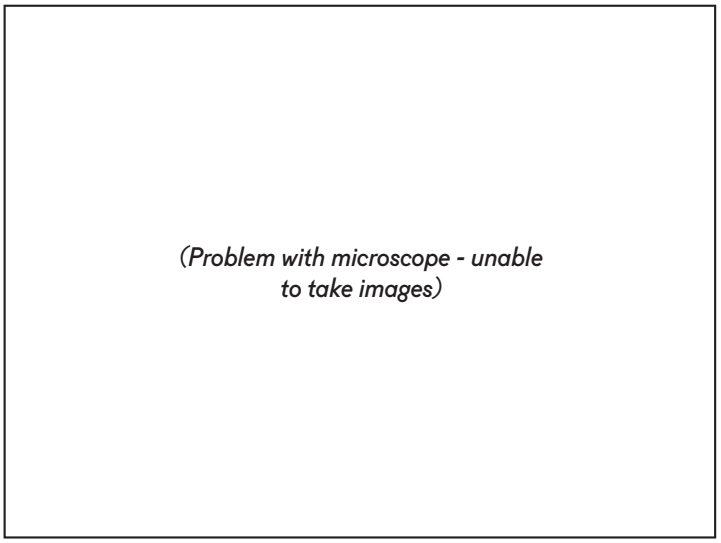
COUCHED



NOTES

- Some elongated cells - only on SeaCell™, with some proliferated.

WRAPPED



NOTES

- Cells somewhat elongated & some suggestion of proliferation

Results - 8 days

TRAPPED FIBRES

(No image taken due to lack of cells)

NOTES

- No apparent proliferation - limited number of cells

MACRAMÉ

(Image lost due to microscope issue)

NOTES

- Cells still visible - not a large amount of further proliferation evident

Scaffolds Experiment 4

DATE	10.08.2016
CELL TYPE	C2C12s *(immortalized mouse myoblast (muscle) cells)*
MEDIA TYPE	DMEM X1 + GlutaMAX *Made by Gibco*
STRUCTURES SEEDED	Three-stranded braid, french knot, satin stitch and couched yarns over monofilament

AIM

To assess cell adherence, viability and orientation on four different textile scaffold structures

---

PROTOCOL

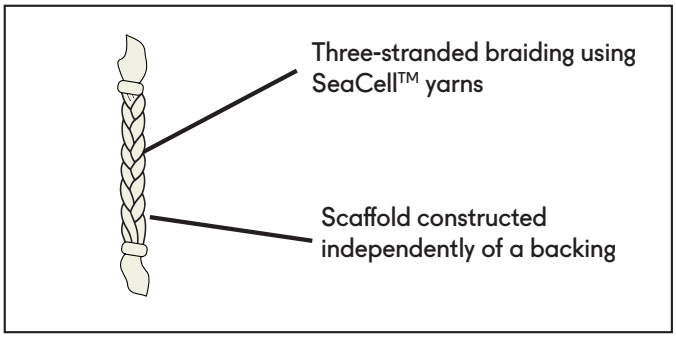
SEEDING

- Grow sufficient number of C2C12 cells to be able to seed all scaffolds - for this experiment each scaffold needs 200,000 cells
- Using sterile tweezers transfer autoclaved scaffolds into separate wells in a 6 well culture plates
- Cover all scaffolds with 0.5% gelatin solution and leave for 10 mins. Remove gelatin solution and leave to dry in hood for 30 minutes.
- Trypsinise cells, count, and then resuspend in the required amount of media - each scaffold should be seeded with 200,000 cells, in 1ml of media.
- Place each individual scaffold into an Eppendorf tube
- Pipette 1ml of media with cells into each of the tubes
- Place tubes in the heated shaker (temp 37°C, speed 600) and leave to shake for 2 hours
- Remove scaffolds from tubes and place in separate wells of a 6 well plate, pipette media from the tube into the well with the material. Add additional media, as needed, if scaffold is not fully covered
- Incubate, and stop at relevant time points - 24hr, 4 days, and 9 days

*F*IXING

- Remove media and add 3ml of PFA to each well, leave for 30 mins
- Remove PFA, add 3ml of PBS to each well, and agitate for 10mins, repeat.
- Add 3µL of phaloid stain to 3ml of PBS - add to each well, cover in foil and shake for 30 mins

SCAFFOLD DIAGRAM*



SCAFFOLD STRUCTURE

SeaCell™ three-stranded plait

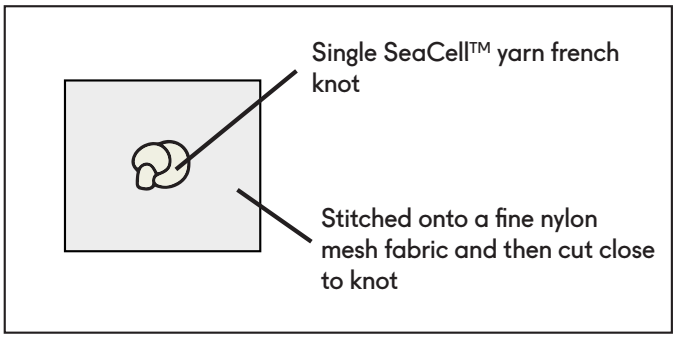
MATERIAL SIZE

SeaCell™ yarn - 320 microns

NOTES

- Material source: http://handweavers.co.uk/shop/seacell--made-from-seaweed--seacell_top.html#SID=169
- Fibre was the most 'wetable' i.e. absorbs water quickly and does not float
- Autofluorescence - does not appear to auto-fluoresce in red or green

SCAFFOLD DIAGRAM*



SCAFFOLD STRUCTURE

SeaCell™ french knot

MATERIAL SIZE

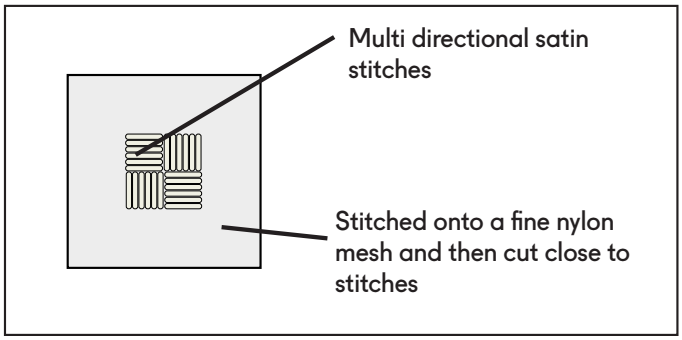
SeaCell™ fibres - 20 microns, nylon filament - 500 microns

NOTES

- Material source: http://handweavers.co.uk/shop/seacell--made-from-seaweed--seacell_top.html#SID=169
- Fibre was the most 'wetable' i.e. absorbs water quickly and does not float
- Autofluorescence - does not appear to auto-fluoresce in red or green

**not to scale*

SCAFFOLD DIAGRAM*



SCAFFOLD STRUCTURE

SeaCell™ bi-directional satin stitch

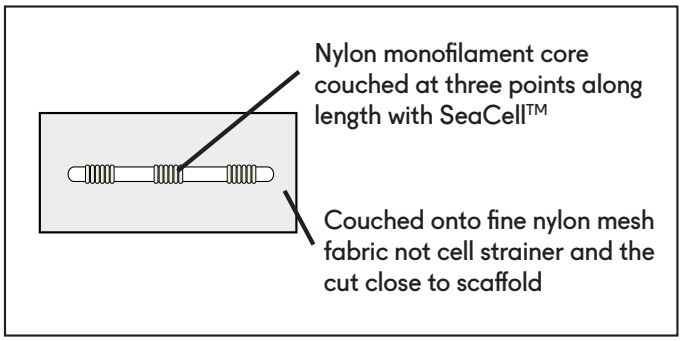
MATERIAL SIZE

SeaCell™ yarn - 320 microns

NOTES

- Material source: http://handweavers.co.uk/shop/seacell--made-from-seaweed--seacell_top.html#SID=169
- Fibre was the most 'wetable' i.e. absorbs water quickly and does not float
- Autofluorescence - does not appear to auto-fluoresce in red or green

SCAFFOLD DIAGRAM*



SCAFFOLD STRUCTURE

Couched SeaCell™ thread over nylon monofilament core

MATERIAL SIZE

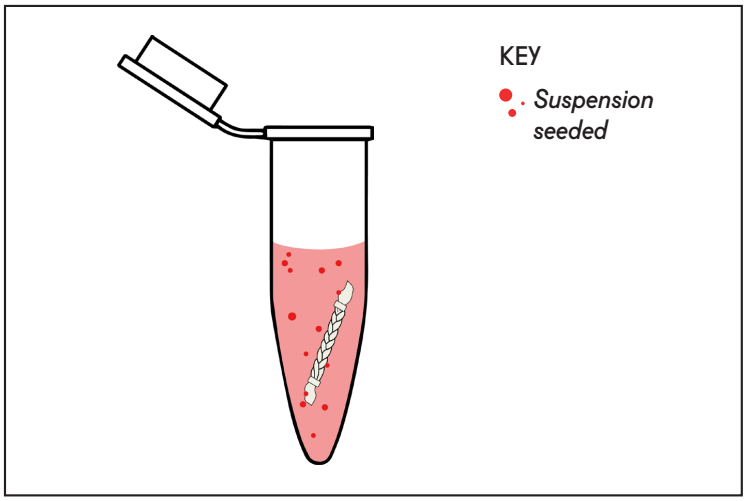
SeaCell™ yarn - 320 microns, nylon filament - 500 microns

NOTES

- Material sources: SeaCell™ as before. Nylon monofilament 'Climax High Quality Filament' http://modelshop.co.uk/
- SeaCell™ as before. Nylon was 'wetable', (didn't float) but it cannot absorb liquid and therefore media and proteins.
- Autofluorescence - SeaCell™ as before. Nylon fluoresced under green, and under red

**not to scale*

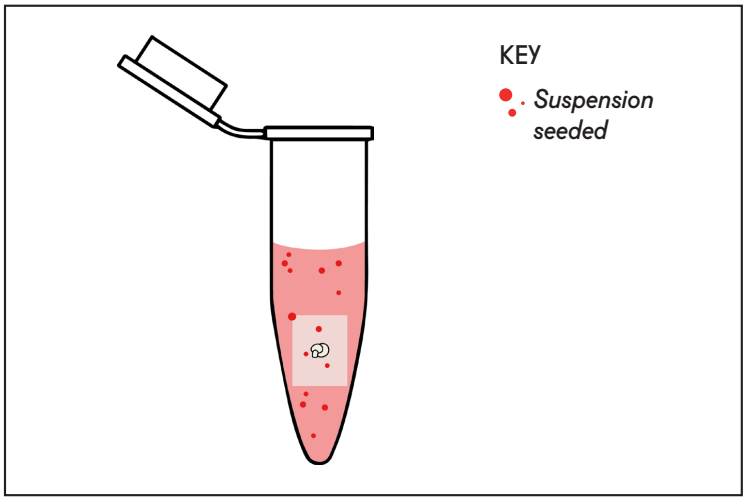
SEEDING



NOTES

- Due to poor results using both microseeding and flood seeding, suspension seeding was used.

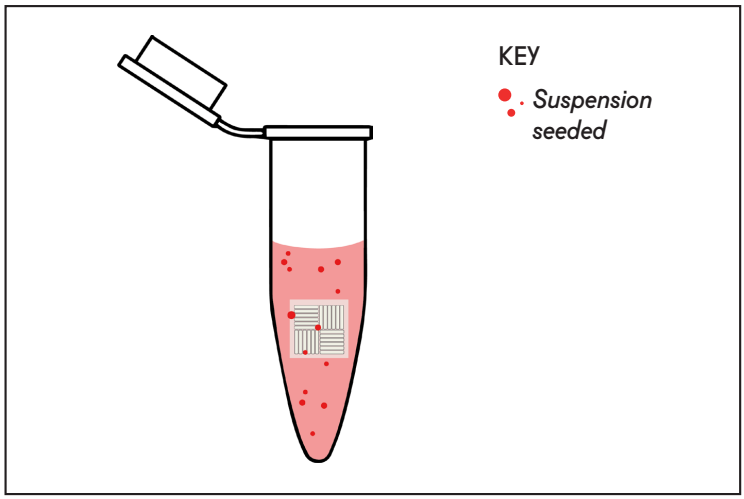
SEEDING



NOTES

- Due to poor results using both microseeding and flood seeding, suspension seeding was used.

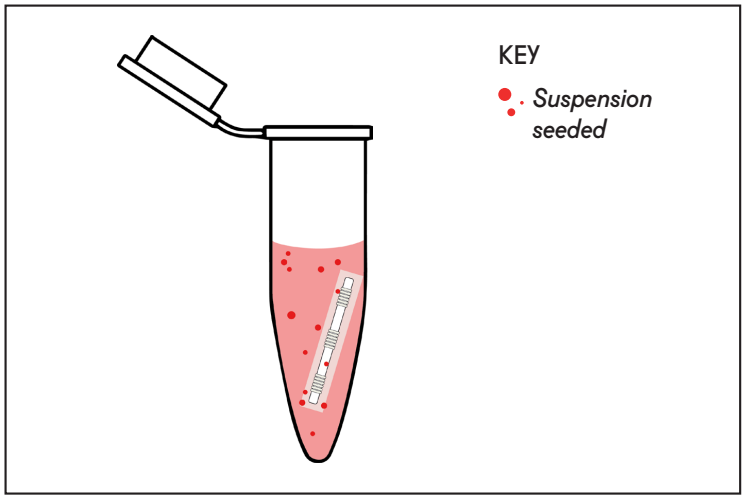
SEEDING



NOTES

- Due to poor results using both microseeding and flood seeding, suspension seeding was used.

SEEDING



NOTES

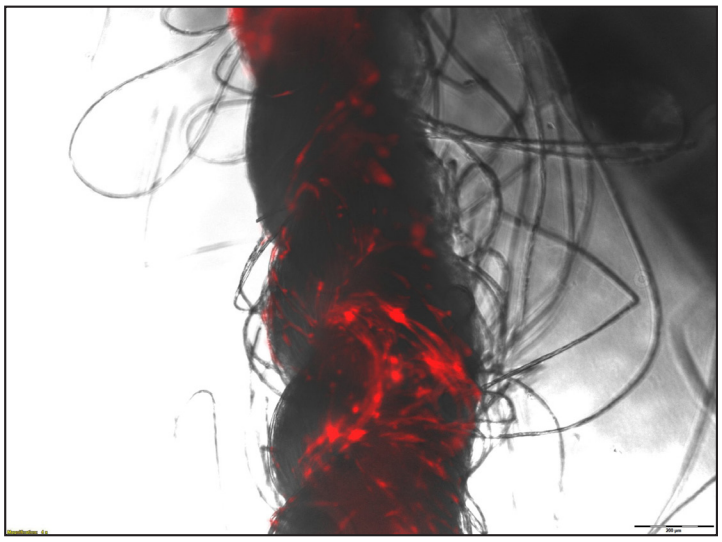
- Due to poor results using both microseeding and flood seeding, suspension seeding was used.

Results - 24 hour

BRAID

x4 magnification

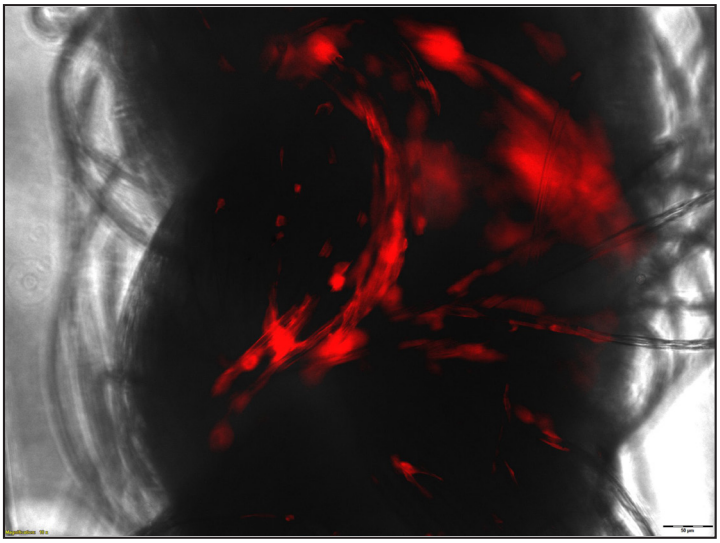
Brightfield image combined with red cell images - composite image 24hrs post seeding



BRAID

x10 magnification

Brightfield image combined with red cell images - composite image 24hrs post seeding



NOTES

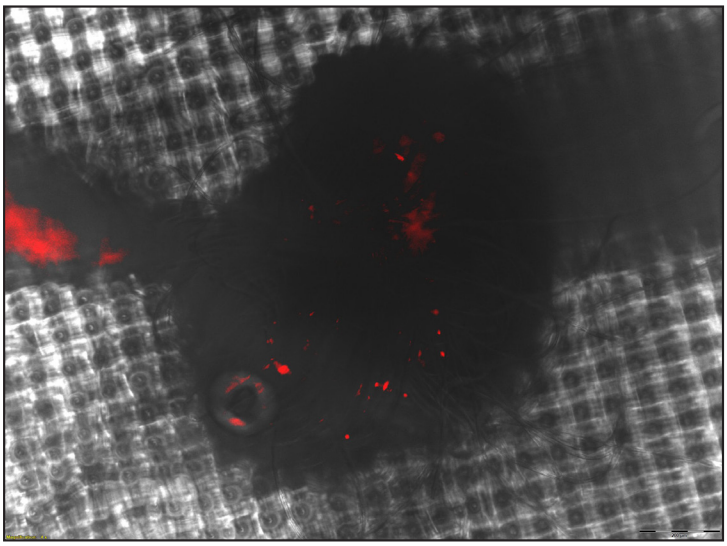
- A large amount cells attached to, and elongating along, the individual fibres within braid. Most successful scaffold so far at 24 hr stage.

Results - 24 hour

FRENCH KNOT

x4 magnification

Red fluorescent light cell image - 24hr post seeding



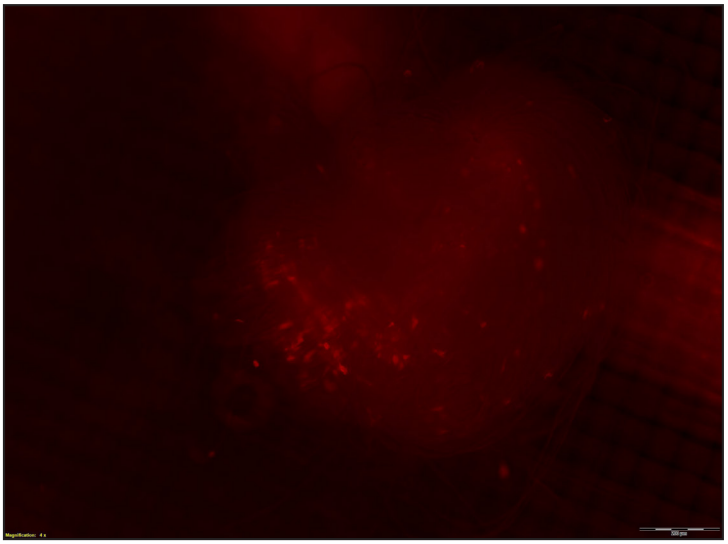
NOTES

- Cells attached to the knot - rounded in morphology

FRENCH KNOT

x10 magnification

Red fluorescent light cell image - 24hr post seeding



NOTES

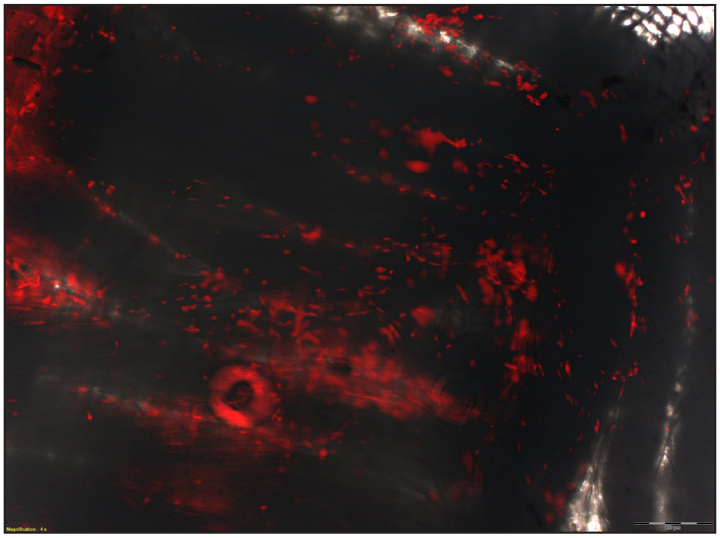
- *(Problem with microscope - only able to take fluorescent images)*

Results - 24 hour

BI-DIRECTIONAL SATIN

x4 magnification

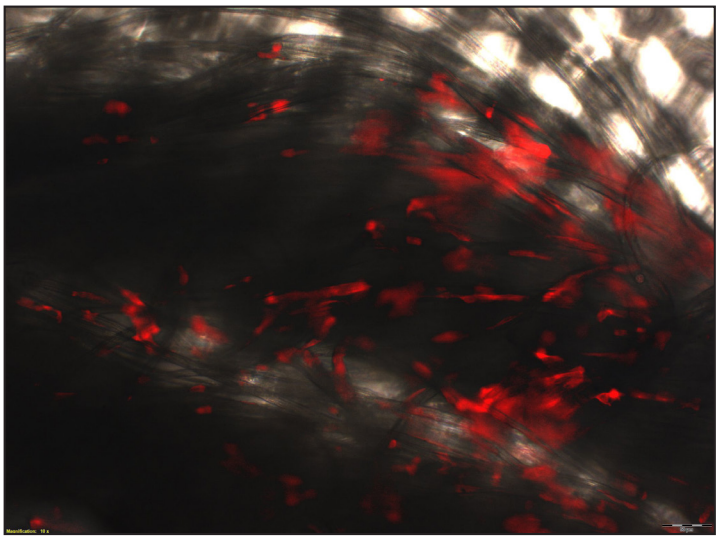
Brightfield image combined with red cell images - composite image 24hrs post seeding



BI-DIRECTIONAL SATIN

x10 magnification

Brightfield image combined with red cell images - composite image 24hrs post seeding



NOTES

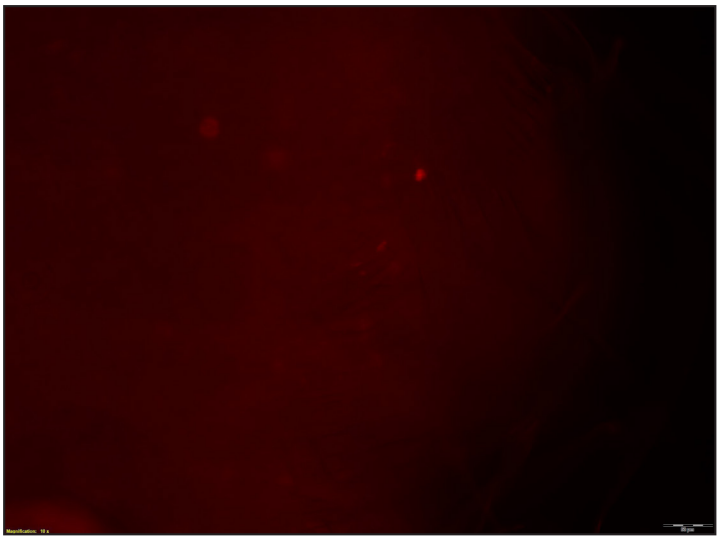
- Large number of cells attached to individual fibres in threads - morphology in between rounded and elongated

Results - 24 hour

COUCHED

x10 magnification

Brightfield image combined with red cell images - composite image 24hrs post seeding



NOTES

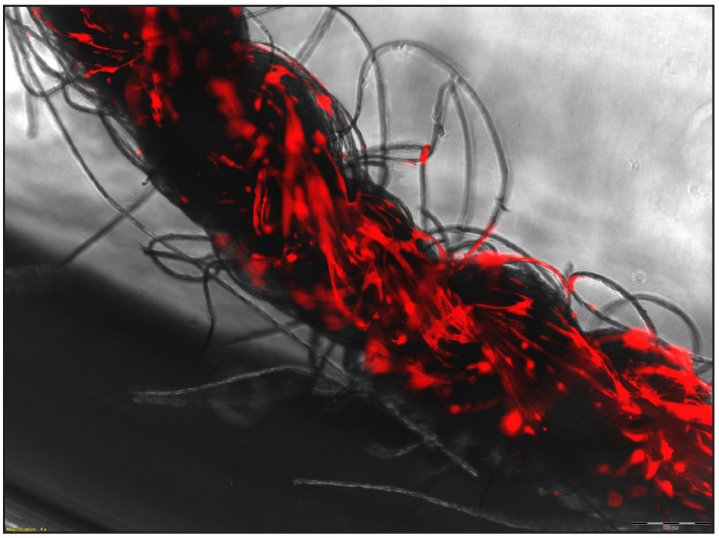
- A reasonable number of cells attached - rounded in morphology and appear to be almost 'embedded' within fibres - difficult to image
- *(Some problems with microscope - where I was only able to take fluorescent images)*

Results - 4 days

BRAID

x4 magnification

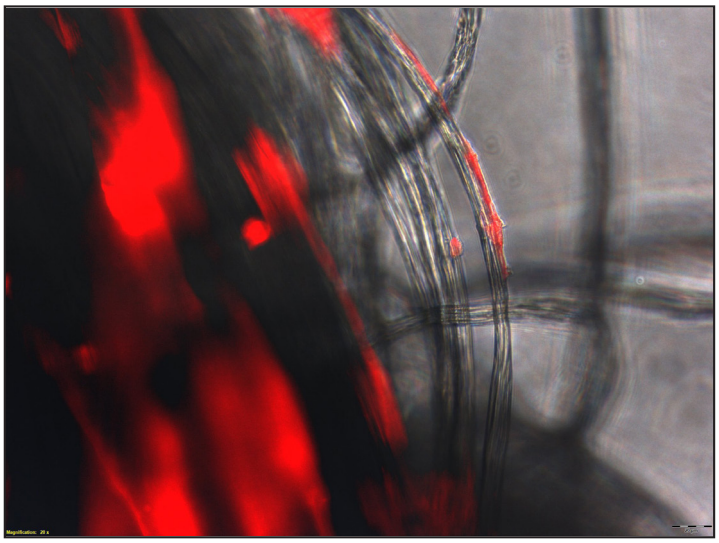
Brightfield image combined with red cell images - composite image 24hrs post seeding



BRAID

x20 magnification

Brightfield image combined with red cell images - composite image 24hrs post seeding



NOTES

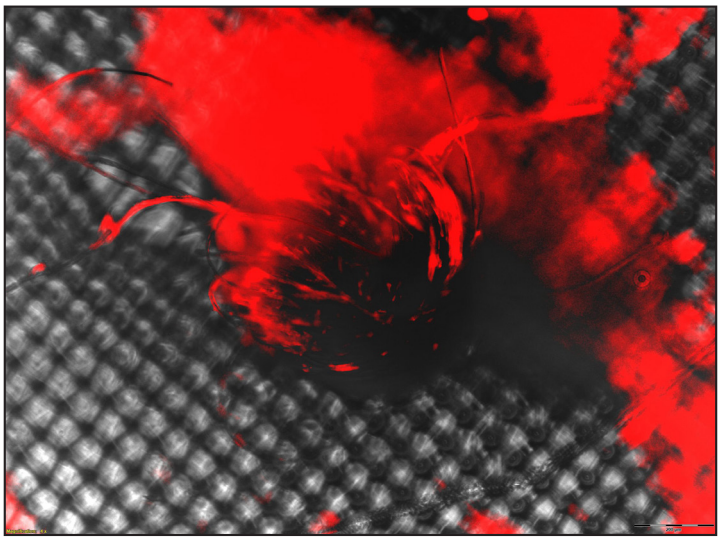
- Cells appear to have proliferated and are elongated along the individual fibres - they have a long branch like morphology

Results - 4 days

FRENCH KNOT

x4 magnification

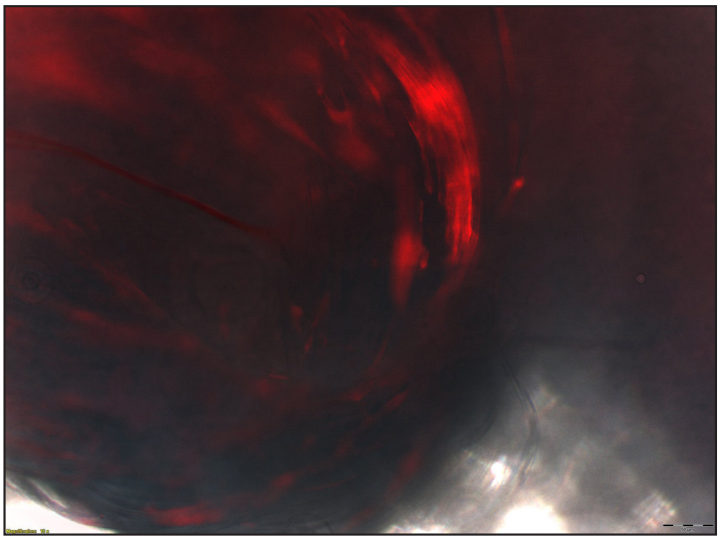
Red fluorescent light cell image - 24hr post seeding



FRENCH KNOT

x10 magnification

Brightfield image combined with red cell images - composite image 24hrs post seeding



NOTES

- Cells have proliferated and have changed from the rounded morphology, becoming elongated and following the direction of fibres

Results - 4 days

BI-DIRECTIONAL SATIN

(Problem with microscope - unable to take images)

NOTES

- Cells appeared to have proliferated and are still elongated along individual fibres

COUCHED

(Problem with microscope - unable to take images)

NOTES

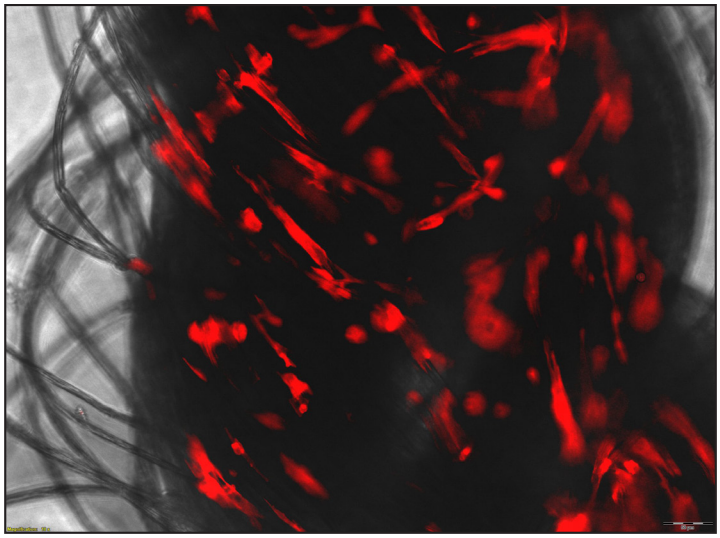
- Difficult to tell if cells have proliferated - still relatively rounded in morphology

Results - 9 days

BRAID

x10 magnification

Brightfield image combined with red cell images - composite image 24hrs post seeding



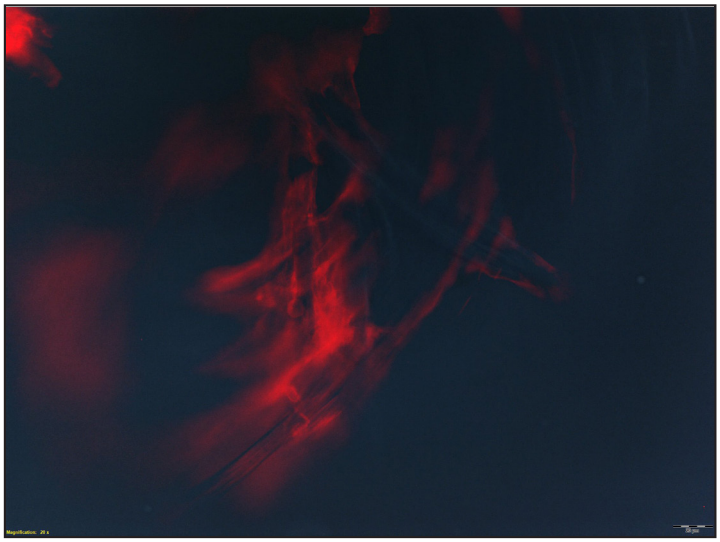
NOTES

- Scaffold still highly populated with cells which are long in morphology and following the direction of the scaffold.

FRENCH KNOT

x20 magnification

Brightfield image combined with red cell images - composite image 24hrs post seeding



NOTES

- Scaffold still highly populated with cells which are long in morphology and following the direction of the scaffold.

Results - 9 days

BI-DIRECTIONAL SATIN

(No image taken due to lack of cells)

NOTES

- Cells appeared to have proliferated a little more and are still elongated along individual fibres

COUCHED

(Image lost due to microscope issue)

NOTES

- Looks as though there are less cells - not sure if they have migrated into scaffold or have not proliferated any further

Scaffolds Experiment 5

DATE	25.08.2016
CELL TYPE	C2C12s *(immortalized mouse myoblast (muscle) cells)*
MEDIA TYPE	DMEM X1 + GlutaMAX *Made by Gibco*
STRUCTURES SEEDED	Crochet, macramé, trapped fibres and three-stranded braid (mixed yarns)

AIM

To assess cell adherence, viability and orientation on four different textile scaffold structures

---

PROTOCOL

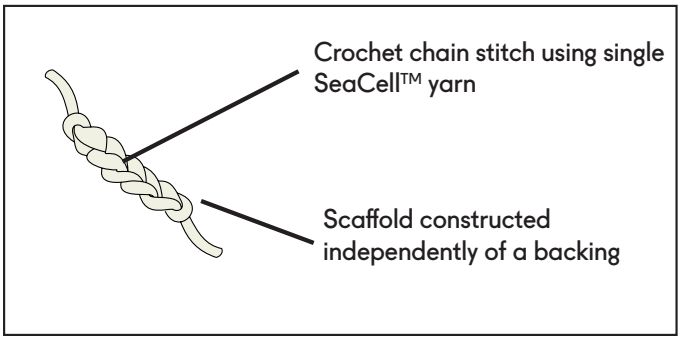
SEEDING

- Grow sufficient number of C2C12 cells to be able to seed all scaffolds - for this experiment each scaffold needs 200,000 cells
- Using sterile tweezers transfer autoclaved scaffolds into separate wells in a 6 well culture plates
- Cover all scaffolds with 0.5% gelatin solution and leave for 10 mins. Remove gelatin solution and leave to dry in hood for 30 minutes.
- Trypsinise cells, count, and then resuspend in the required amount of media - each scaffold should be seeded with 200,000 cells, in 1ml of media.
- Place each individual scaffold into an Eppendorf tube
- Pipette 1ml of media with cells into each of the tubes
- Place tubes in the heated shaker (temp 37°C, speed 600) and leave to shake for 2 hours
- Remove scaffolds from tubes and place in separate wells of a 6 well plate, pipette media from the tube into the well with the material. Add additional media, as needed, if scaffold is not fully covered
- Incubate, and stop at relevant time points - 24hr, 4 days, and 9 days

FIXING

- Remove media and add 3ml of PFA to each well, leave for 30 mins
- Remove PFA, add 3ml of PBS to each well, and agitate for 10mins, repeat.
- Add 3µL of phaloid stain to 3ml of PBS - add to each well, cover in foil and shake for 30 mins

SCAFFOLD DIAGRAM*



SCAFFOLD STRUCTURE

SeaCell™ crochet

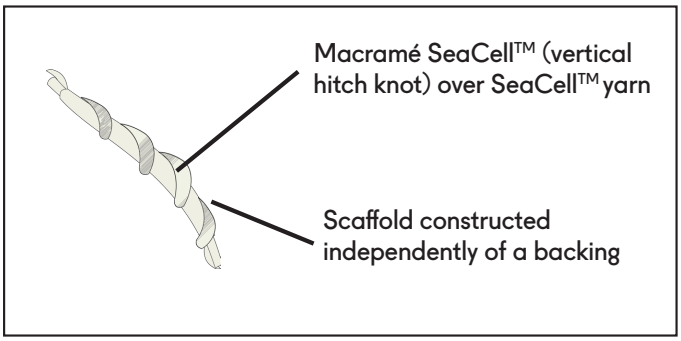
MATERIAL SIZE

SeaCell™ yarn - 320 microns

NOTES

- Material source: http://handweavers.co.uk/shop/seacell--made-from-seaweed--seacell_top.html#SID=169
- Fibre was the most 'wetable' i.e. absorbs water quickly and does not float
- Autofluorescence - does not appear to auto-fluoresce in red or green

SCAFFOLD DIAGRAM*



SCAFFOLD STRUCTURE

SeaCell™ macramé

MATERIAL SIZE

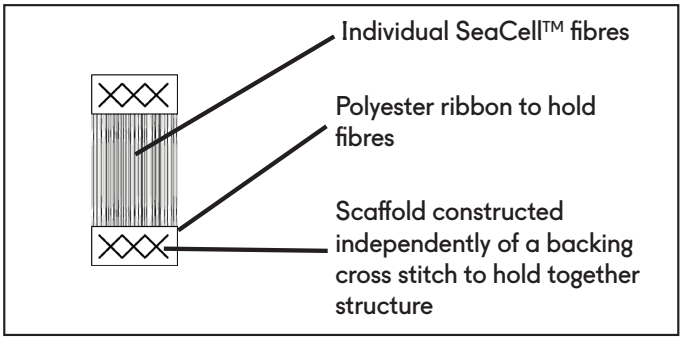
SeaCell™ yarn - 320 microns

NOTES

- Material source: http://handweavers.co.uk/shop/seacell--made-from-seaweed--seacell_top.html#SID=169
- Fibre was the most 'wetable' i.e. absorbs water quickly and does not float
- Autofluorescence - does not appear to auto-fluoresce in red or green

**not to scale*

SCAFFOLD DIAGRAM*



SCAFFOLD STRUCTURE

SeaCell™ narrow trapped fibres

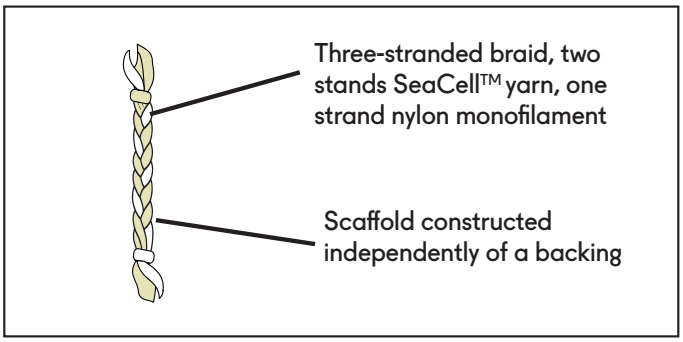
MATERIAL SIZE

SeaCell™ fibres - 20 microns

NOTES

- Material source: http://handweavers.co.uk/shop/seacell--made-from-seaweed--seacell_top.html#SID=169
- Fibre was the most 'wetable' i.e. absorbs water quickly and does not float
- Autofluorescence - does not appear to auto-fluoresce in red or green

SCAFFOLD DIAGRAM*



SCAFFOLD STRUCTURE

SeaCell™ and nylon monofilament three-stranded braid

MATERIAL SIZE

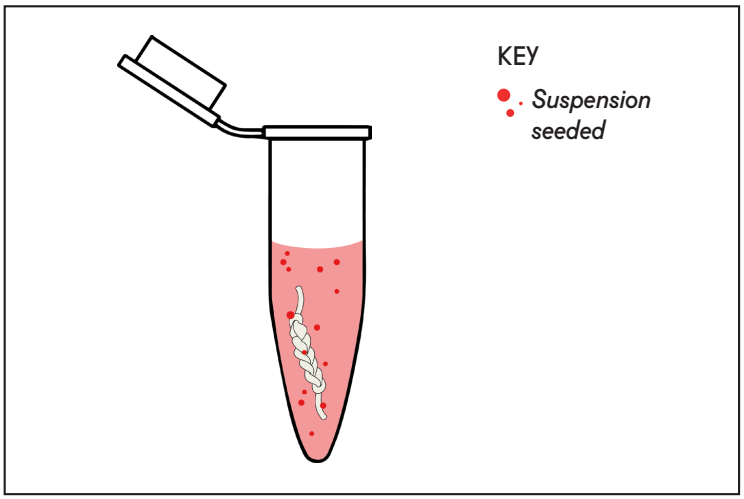
SeaCell™ yarn - 320 microns, nylon filament - 300 microns

NOTES

- Material sources: SeaCell™ as before. Nylon monofilament 'Climax High Quality Filament' http://modelshop.co.uk/
- SeaCell™ as before. Nylon was 'wetable', (didn't float) but it cannot absorb liquid and therefore media and proteins.
- Autofluorescence - SeaCell™ as before. Nylon fluoresced under green, and under red

**not to scale*

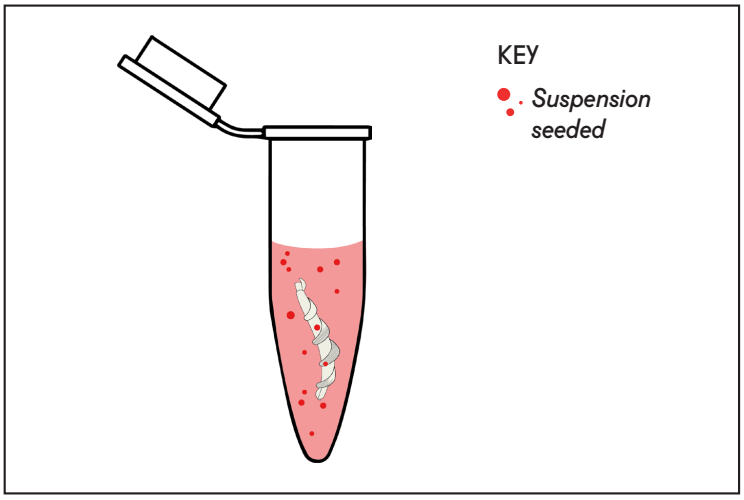
SEEDING



NOTES

- Due to poor results using both microseeding and flood seeding, suspension seeding was used.

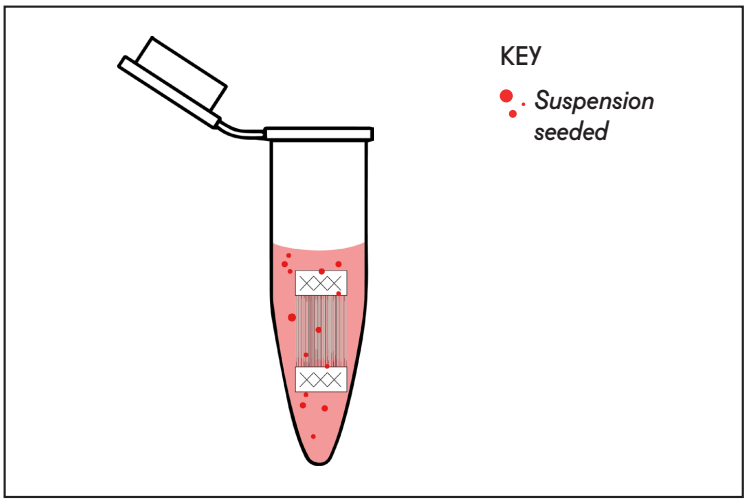
SEEDING



NOTES

- Due to poor results using both microseeding and flood seeding, suspension seeding was used.

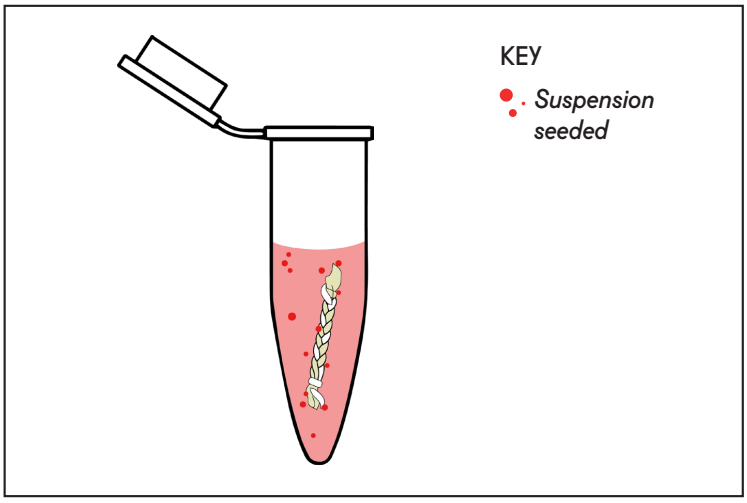
SEEDING



NOTES

- Due to poor results using both microseeding and flood seeding, suspension seeding was used.

SEEDING



NOTES

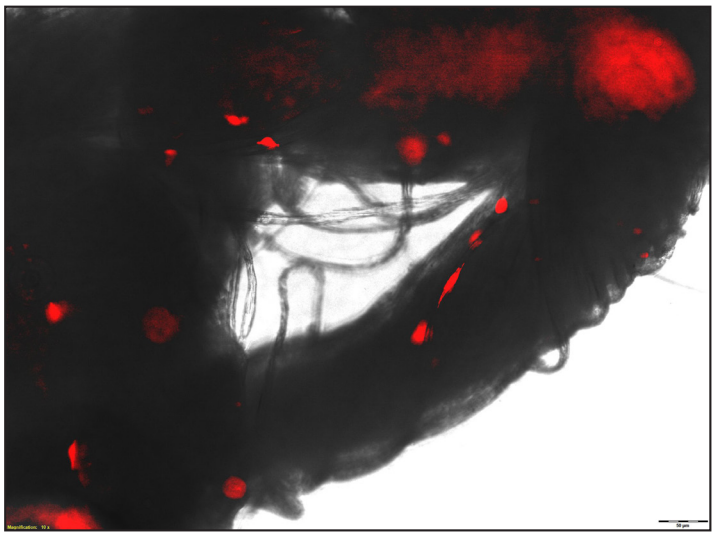
- Due to poor results using both microseeding and flood seeding, suspension seeding was used.

Results - 24 hour

CROCHET

x10 magnification

Brightfield image combined with red cell images - composite image 24hrs post seeding



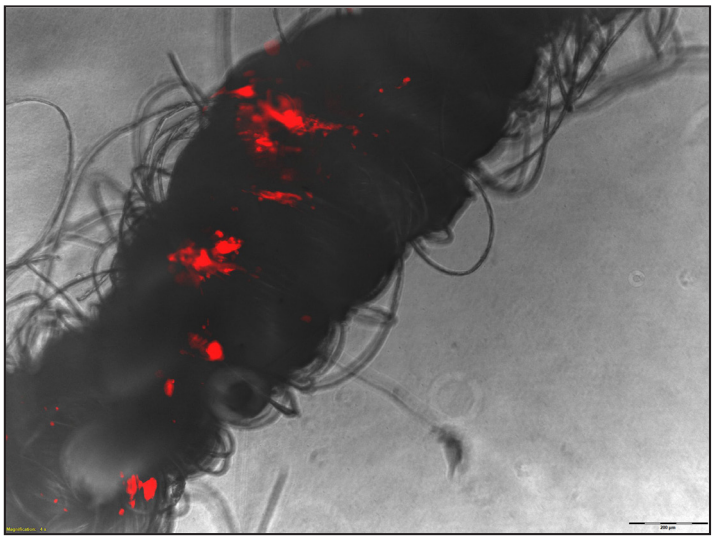
NOTES

- Some cells attached to scaffold, some slightly elongated

MACRAMÉ

x4 magnification

Brightfield image combined with red cell images - composite image 24hrs post seeding



NOTES

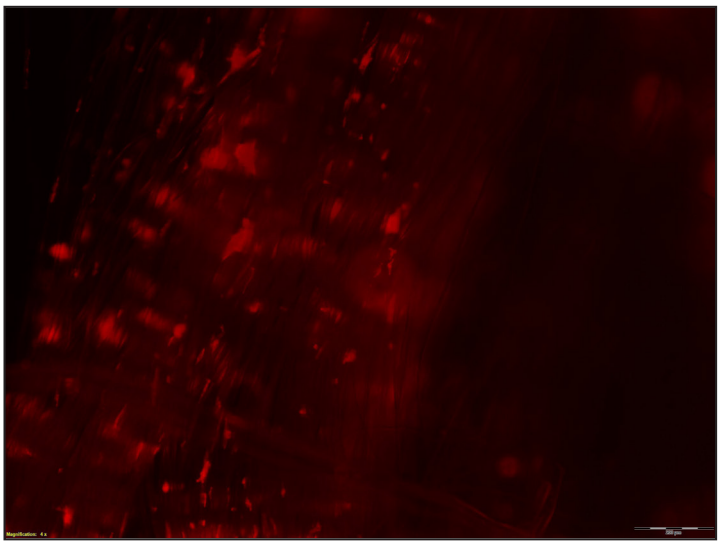
- Some cells attached and are sitting in the valleys between threads which are created through macramé technique

Results - 24 hour

TRAPPED FIBRES

x4 magnification

Red fluorescent light cell image - 24hr post seeding



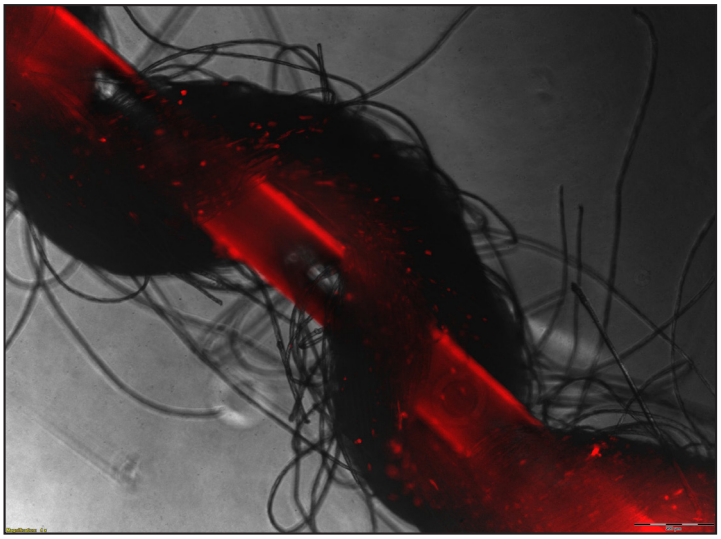
NOTES

- A large number of cells attached and embedded within scaffold structure - elongated along fibres

3 STRANDED BRAID MIXED

x4 magnification

Brightfield image combined with red cell images - composite image 24hrs post seeding



NOTES

- A good amount of cells attached only on the SeaCell™ - no cells visible on nylon monofilament
- *(Autofluorescence of monofilament makes whole thread look red)*

Results - 4 days

CROCHET

(Problem with microscope - unable to take images)

NOTES

- Cells have elongated slightly and have proliferated a small amount. Following fibre directionality.

MACRAMÉ

(Problem with microscope - unable to take images)

NOTES

- Cells elongated slightly and proliferated a small amount within valleys of scaffold

Results - 4 days

TRAPPED FIBRES

(Problem with microscope - unable to take images)

NOTES

- Lots of cells still attached and elongated along individual fibres. Also connected across between fibres

3 STRANDED BRAID MIXED

(Problem with microscope - unable to take images)

NOTES

- Cells still only growing on SeaCell™ - elongated further than they were at 24 hours. Some suggestion of proliferation

Results - 9 days

CROCHET

(Problem with microscope - unable to take images)

NOTES

- Cells have proliferated a little more - may be difficult as there are large gaps between different parts of the structure?

MACRAMÉ

(Problem with microscope - unable to take images)

NOTES

- Cells appear to have not proliferated much more - may be confluent within the valleys where they are attached and therefore not dividing.

Results - 9 days

TRAPPED FIBRES

(No image taken due to lack of cells)

NOTES

- Lots of elongated cells still attached, unsure if there has been further proliferation

3 STRANDED BRAID MIXED

(Image lost due to microscope issue)

NOTES

- Good number of cells still attached - no cells visible on the nylon monofilament

APPENDIX 5

INTERVIEW WITH PROF. DI SILVIO
PROF. CAROLE COLLET & MYSELF

ORIGINS OF THE COLLABORATION:

Carole: Amy - how did the collaboration come about? And Lucy what drew a Professor in tissue engineering to allow a textile designer access to their lab?

Amy: I really wanted to find an interdisciplinary laboratory that was looking at a range of techniques and approaches.

Lucy: There's a big drive for an interdisciplinary approach within the sciences now.

Carole: That's true, collaborations.

Lucy: Collaboration, exactly, you've got to demonstrate that you're reaching out across different disciplines. Science and art are interlinked; both attempt to describe knowledge of a different sort yet they are linked. Both of them are creative; science allows the acquisition of knowledge in a more objective manner, whereas art expresses knowledge in a more subjective way. Art creates in one way, science creates in another, and they meet somewhere in the middle, and I think one should embrace the other.

I've learned from Amy, and I hope that Amy has learnt from me.

Amy: Oh absolutely - I was so fortunate to find Lucy's lab and that she agreed to let me in! Even though I think it was a little left of center as an ask initially!

Lucy: I think initially I was a little skeptical and it wasn't until Amy almost forcefully said, "Oh can I just come and have a chat with you," that seriously, suddenly my whole attitude changed, and I started to realize that there is a whole new world out there, that as scientists we live in quite a blinkered world ... I think what you're doing is bringing the scientists out of the lab.

Carole: What were those initial conversations and how did that change your perspectives?

Amy: When I first met with Lucy I took a range of my previous work to show her. Both from an earlier residency I had completed at SymbioticA, where I first learnt to do tissue culture, and some of my speculative work exploring the future of haute couture. The Biological Atelier work, which I had come to a point with where I wanted to move away from speculation into practical exploration, was actually useful as a conversation starter. The visuals, and pieces, I'd created helped to articulate what my questions were around the potential of tissue engineering and why a designer might be interested in working in a scientific laboratory. However, I already knew at that point that the technology was a long way off realizing those speculative prototypes and that the research would focus much more on the fundamentals of what a design-based approach could bring to the lab. [Figure 1]

CRAFTING THE BODY: INITIAL EXPERIMENTS AND THE IMPORTANCE OF MATERIAL EXPLORATION

Carole: A key parallel I think is interesting is the link between textile craft and the repair of the body.

Amy: There is a really close relationship between textiles and the body, and we've been 'crafting' our bodies, both for repair and aesthetically, for millennia. I think the earliest examples that I found when researching this was somewhere in India around the sixth century BC. However, it's really difficult to pinpoint because both textiles and bodies are things that decompose – so who knows if we've ever found the first example. In addition to this there are obviously strong links between current surgery methods and centuries old textile techniques – for example in the stitches used to suture. You can look in a medical textbook or a textile one and you'll find a blanket stitch. [Figure 2]

Lucy: Oh absolutely. I mean that's where it was taken from. If we look back in ancient cultures natural materials were used for suturing wounds, treating diseases and as implants in the body

Amy: It's that crossover that started my fascination in this area – I saw an embroidered medical implant and became obsessed with how my skillset as a textile designer could be used in different disciplines. For example, traditional stitches being used to mimic natural structures found within the body.

This was the approach we took in the initial work together – we we're looking at the anterior cruciate ligament. [Figure 3] I was using textile techniques to mimic the structure of that part of the body. However, I went too complex too quickly. I was making scaffolds to seed cells onto without understanding the basics - I needed to take a step back and understand how the materials behave on their own, how the different structures change their behave, and then understand how it could be applied to different areas. I think that was a really important shift when I went back to a more iterative design approach. I don't know if the research would have got to anywhere near as interesting a place if I'd kept trying to say, "I'm going to make this particular thing."

Carole: So what is it that you got out of it, in design terms, that you would not have acquired otherwise?

Amy: I think anyone who goes into a lab who's not got a scientific background, at some point will feel the temptation to try to become a tissue engineer, or to become more and more scientific, because you know that your skillset is different, and you're in this very new environment. However, it was the most important process to go through and realize you need to approach things the same way you would outside of the lab, but with the skills you've learned working in the lab. So rather than trying to fit myself into what I thought I should be doing in the lab, I learned to say "okay, let's go back to that craft way of working – approach this as a maker."

And that's when interesting things really started to happen.

Lucy: Absolutely, tissue engineering is transforming the way we look at tissues and repair, we now talk about regeneration. At the core, tissue engineering is about designing and constructing physical objects like hearts, lungs, livers etc. This requires “building skills” and biological ones, essentially scientists need to be trained to be craftsmen.

Amy: And I think I came to realize that it's actually having the rigor you learn from the process of structuring experiments isn't uncreative it actually helps you be creative faster. Because you are saying, "Okay, I'm going explore this area of materials, and then I will learn something from that, and then I'll be able to iterate faster, because I've not had so many different factors in there that I can't possibly tell what made it successful or not successful."

DEVELOPMENT OF THE RESEARCH: TEXTILE CRAFT TECHNIQUES:

Carole: How did you approach the work in the laboratory differently after the initial experiments?

Amy: I took it right back to basics – what materials will cells grow on and which won’t they. This simple question led to the creation of a materials archive with different materials all seeded with the same cells, in the same way. There were 10 different fiber types tested from across the textile spectrum. But in many ways it's a small snapshot, a start of what could be a much larger research and constantly ongoing research.

Interestingly however, one of the key learnings in this part of the research was the importance of size and that's one of the things I found most fascinating was understanding the relationship of scale.

Lucy: Scale is so important. Cells in their natural microenvironment respond to a multitude of signals, such as biophysical cues in the form of change in topography or stiffness. It can almost be a selective mechanism, whereby you select a specific topography to bring about a specific cell response to that scale. Microscale topographies can change the way a cell adheres and migrates across it’s surface. Different cell types will respond differently to these cues, and the cellular cytoskeleton can reorganize itself depending on the feature size.

One of the problems we have when we make porous materials, is that we need to make sure that we've got micro and macro porosity and that these pores are interconnected to ensure cells can migrate down the material. Also different size cells have to migrate such as osteoblasts (bone cells) and endothelial cells,responsible vasculature.

Amy: I think it's so interesting, and I know that when talking to different researchers in the lab when I was there, that each cell type behaves differently, and it made me want to keep screening because you might find that one material works on cell type and not on the other!

Lucy: This is another key area, which is bio-selectivity, and all materials will have different characteristics to which the cells will selectively respond.

Amy: And that's really, really interesting. Because it brought up ideas of concepts like textile resist - and that the understanding of what scale the cells that you're working are at, the scale of the thread, and then what they would and won't attach to allows you to start constructing a scaffold, which not only helps the cells to align, but also controls where they will and won't attach. [Figures 4, 5 & 6] Which all relates directly to the traditional process of textile resist - when you're dyeing, you want to have dye go in one area and not in the other. It's really interesting to have those very traditional craft skills, and ways of thinking, be applied in something like tissue engineering that seems on the surface so radically different. [Figure 7]

Amy: This also links to one of the final outcomes of the research, which were the illustrations that I commissioned because most of the stuff we did, you look down a microscope to see - you're working with things you can't even see with the naked eye. And because you're working at such a scale, it's hard to communicate the ideas visually to people.

Lucy: But you're not really at an end point yet, if anything you're just at the beginning!

Amy: Absolutely, but it's still important to think about how to communicate the work and it's outcomes to those outside of the lab.

Carole: The products you're creating, I call them silent interfaces. Because they're silent in the body, they're not active, but they are supporting the activity of the cells growing in alignment.

Lucy: Well in scientific terms we talk about tissue interfaces. Tissues exist as multiple types and are assembled in a complex organ system. Tissues interface with a seamless integration, with the tissue- to -tissue interfaces exhibiting a gradient of structures and properties that serve a number of functions. Successful tissue engineering requires a direct structural interface with the host tissue.

Carole: Ah so that's interesting.

Amy: I think that's one of the things I remember from the very early, going back to how this all began, is when I came into your office and you talked that nothing in the body grows in isolation - everything is interfacing or integrating with something else. And when you work in a lab one there's sometimes that danger that you end up working with one cell type on its own, and it's never that way in the body.

Lucy: I think that's a really important point that you bring up. Because even scientists, everyone is specialized in their area "I'm a soft tissue biologist," "I'm a hard tissue biologist." etc. But no tissues exist in isolation. So, when you are developing your tissue-engineered bone for example, you've got to

think of what tissue that's going to interface with, and it's going to interface with soft tissue.

Amy: I think that links back in some way things about textiles and creating. When you're working with materials, many times you're trying make something or a product where you're not just working with one type of material. You're trying to construct something with materials of different characteristics and working with how those materials wants to behave.

Carole: So effectively you've designed an ecosystem - a textile-based ecosystem that will support the living cellular system. Because the ecosystem is not just a fiber, it's the structure also.

Lucy: The aim of tissue engineering is the desire to regenerate tissues that mimic nature, which does it very well. Scientists are inspired by natural structures - we have this desire to create tissues that look like, and behave like, natural tissues ... and I'm a biologist, so my main interest has got to be biologically responsive, biologically receptive materials that integrate with natural host tissues. However, if you speak to an engineer, or a material scientist, they'll say, "Oh no, strength is the most important thing, it's got to be strong!" And we're coming at it from quite opposing ends

Lucy: Amy, did you also look at some morphology changes in cells?

Amy: I did, and I did observe some.

Lucy: Because I thought I saw some pictures where cells were different shapes.

Amy: They were. And they were different shapes depending on the diameter of the thread that they were seeded onto – it would affect how they would either elongate-

Lucy: Whether they would spread out or get long?

Amy: Or if they'd stay as more of a 'blob', to use a technical term! To support those findings, I read a couple of papers on thread diameter how that affected alignment of cells. I found that mine matched up with what they've found, but I never found anyone take it any further than that. Because for me as a textile designer, if I know what scale of thread causes alignment, I can then start to design structures that use that knowledge. For example, if I want them to go one way versus the other way. And that's where I think that making knowledge comes into play of knowing how to structure a textile.

Lucy: See that kind of information would be of extreme importance to as scientists trying to design scaffolds.

Amy: And I also think it's about quick iteration as well, because if you know how to make something you don't have to wait to source it from somewhere. To be able to say, "Okay that didn't work," and make another one very quickly, is also something that's different I think?

Lucy: It is. We'll make a material and we'll test it and test it it to death, and we'll say, "Oh dear it didn't work, what do you think it was?"

Carole: It's actually creatively reconsidering how you can rethink the basics of tissue engineering with cell attachment, using an in-depth textile knowledge to generate a set a research tools. The material archive you created by testing a range of natural and artificial fibers has not been done before. Your PhD project is not a science communication project, it's a real design project, that is actually pushing both the design and the tissue engineering fields.

Amy: So, for me that ability to quickly iterate and develop new scaffolds, learning from the previous ones, is a real example of design playing a unique role in the laboratory.

THE IMPORTANCE OF MULTIDISCIPLINARITY AND CREATIVE FREEDOM:

Carole: What would you say is one of the key learnings of this collaboration for your lab?

Lucy: I think for us it will be that, we want to get as close as we can to nature and trying to understand normal repair mechanisms, normal materials. Everything is about bio-mimetic materials, bio-mimicking nature. Materials that nature will recognize as self. And so, I think we look to quite a few natural materials, and that is a plus, because we want to move towards them.

But I think more importantly Amy demonstrated, where she worked with different threads and different structures, a concept that we know but we don't really understand - which is that you can actually tailor make a patch, a pad, an implant, to make your cells go where you want them to. For example, nerve cells have to go in a specific direction or you won't get regeneration. Other cells you know you can randomly put them there and they will organize themselves into a structure.

Carole: I think that's one of the legacies, is that you've created that hybrid experiment between a science, and the notion of experimentation in design. And I think in terms of design methodology, that's a contribution to knowledge as well - establishing how do you do that without compromising on the rigor of the scientific protocols but managing to open up new ways to think about experimentation.

Lucy: I think you're also making us look at our science with different eyes. I mean now it is very empirical data, graphs, results, asking “what have I discovered?” But you've given us the freedom almost. And you’re really genuinely interested. And because you're genuinely interested and genuinely passionate about what you're doing, I think it gives a scientist that freedom of expression too. And not being afraid to be innovative and say, "Yeah, that sounds like a good idea."

Amy: The notion of freedom is an interesting one and is something that's come up with numerous scientists I've spoken too. Most noticeably the lack of it in current research – which seems to come as a result of department's research focus and I'm sure ultimately funding. It's was incredible to be able to experiment without having a prescribed end goal.

Lucy: And I think the other thing is, it was an evolving thing, wasn't it? So that pressure being removed, there's suddenly this freedom of, "wow, that's interesting, let's look at that. Or maybe we should try that." Whereas you can only do that to a certain extent when you have a defined project. You've got a limited amount of money to do a limited project, you've got to come out with something at the end. And this freedom of being innovative and thinking outside the box, it is a luxury, as far as I was concerned, to be able to think that way.

Amy: One of the other things that has emerged from doing the research, and this is a generalization but relates to end goals, is the idea of top-down versus bottom-up. And I think a lot of science is driven by something that's top-down. Because of funding, because of the research remits and the stress you all under. There are specific issues you're trying to address - so it's about knowing you're trying to fix 'x', and then asking the subsequent question "so how do we get there?"

Whereas I came in going, "I want to start from the opposite end of the spectrum. I'm not saying I'm going to try and do 'x' or fix this problem, I'm going to explore, which is very much a design 'sampling' approach. And then through that understand what it that knowledge could be used for or applied to." It allows you to build a scaffold for potentially a number of different applications rather than taking the other approach where you only make one for a specific purpose.

Lucy: Normally in science we create and design an experiment to answer a specific question ... I mean, for example, one of the things we're working on at the moment is a 3D-printed scaffold so that it mimics natures structure and we are trying to functionalize it, i.e. make it biologically more responsive so that it behaves like natural tissue. And we do the experiments knowing what we want to achieve at the end, and if we don't achieve that we're going to be grossly disappointed, so will our funders be. So, there's that pressure if you've got to get to that finite point.

Carole: You know the answer before you have the question.

Lucy: Well you presume you know, but often get surprises!

Carole: This approach enables to keep the question remaining open.

Lucy: Yes, exactly that.

Carole: So, finally touching again on the legacy of this project, would you consider employing a textile designer in your lab?

Lucy: Absolutely.

Amy: Well, I can't ask for any more than that! I hope from my side, that the legacy of the of project is that more of this type of work is carried out. There's so much potential opened up by these types of collaborations and by a multidisciplinary approach to all aspects of the scientific and creative fields.

APPENDIX 6

ETHICS FORMS

University of the Arts London

RESEARCH ETHICS SECTION ***to be completed if your research involves working with participants***

Further guidance on data protection requirements, informed consent and participant information sheets together with a model participant consent form which can be downloaded from http://www.arts.ac.uk/research-ethics/.

1. Will the participants be: (please tick as appropriate)

Students at the University	
Staff at the University	
Other (please specify)	Audience members of round table discussions and presentations of the practice led research, such as public lectures or conferences.

2. How will participants be recruited and how many will be involved?

Organised round table discussions, and or, presentations will be advertised through email invites, and coverage online and in college. Or I will apply to speak at relevant conferences or events. The number of participants is dependant on how many attend and how many of these people choose to participate in the discussions.

3. What will participants be asked to do? (Explain in terms appropriate to a lay person)

Participants will be asked to join in the debate proposed by the work shown, and encouraged to offer their opinions on the possible use of tissue engineering as a means of redesigning the body. Only those who want to comment will be asked to do so.

4. What potential risks to the interests of participants do you foresee and what steps will you take to minimise those risks? (A participant's interests include their physical and psychological well-being, their commercial interests; and their rights of privacy and reputation).

There are no foreseen potential risks to participants, as all events will be held in safe public institutions such as Universities or lecture theatres. There is also no potential risk to privacy or reputation, as participants will remain anonymous.

5. What potential risks to yourself as the researcher or research student do you foresee and what steps will you take to minimise those risks? (e.g. does your research raise issues of personal safety for you or others involved in the project, especially if taking place outside working hours or off University premises)

There are no foreseen risks to the research proposed.

6. Please attach a copy of proposed written consent form and information sheet to be given to participants. If you are not obtaining written consent or supplying an information sheet, please explain the reasons for this.

Attached N/A

I will not be obtaining consent for two reasons, one is the 'light touch' approach laid out in the UAL Research Ethics Guidelines. The participants will remain anonymous and by attending the event they are choosing to be part of the event, they also have the right to not raise any points during discussions. I will make it clear in any

advertising of events that it is part of my PhD research. Also at the start of any presentations I will state that I may use some comments within my work, but that these will remain anonymous and that anyone wishing to participate and not be quoted to please let me know, or alternatively not participate in any debate. The second reason I will not be asking for written consent is for practical reasons of being unable to obtain this from all participants, especially if it is at a conference that I am attending.

7. Does your project involve children or vulnerable adults e.g. a person with a learning disability? ~~YES~~/NO

If YES,
you must refer to the Guidance on Research Ethics Approval document at http://www.arts.ac.uk/research-ethics/ and obtain a Criminal Records Bureau (CRB) check. Please tick to confirm this has been obtained: ☐

It is a presumption of academic research that, wherever possible and feasible, the raw data on which the research is based should be preserved, so that it can be made available to future researchers who may wish to scrutinise the work. You may also discover at some later stage that you wish to do further work on it yourself. However, the privacy of participants must be respected. Please refer to the guidance note on data protection at http://www.arts.ac.uk/research-ethics/ before answering the questions in the next section. Please consider the value of coding and the strict separation of personal identifiers (e.g. name, address, date of birth) and information of importance to the research, into two separate databases and whether this should involve irreversible anonymisation of the research data by destroying, or failing to create, a linking key. Consider the importance of secure storage of personal information, especially personal identifiers and sensitive data (e.g. records of health, origin, criminal record, etc) during the course of the research and the need for its disposal subsequently.

8. Will you be obtaining personal data from any of the participants? ~~YES/~~NO

If YES:

(a) Give details

(b) How will you store and use this information during the course of your research?

(c) What parts of this information will be confidential?

(d) Will you separate personal identifiers from other (coded) personal data, and if so how will you safeguard the key?

(e) Will personal data be irreversibly anonymised or, if you have separated the data, will the linking code between the two databases be destroyed?

(f) At the conclusion of your research:

(i) Which of your data sets do you intend to retain personally for use in future research?

(ii) Which do you intend to archive for other researchers?

(iii) Which do you intend to destroy?

(g) DEPENDING ON YOUR ANSWERS TO (f):

(i) If you intend to retain certain data sets for future use or to archive them:

(i.i) How will they be stored?

(i.ii) Will participants be informed what data will be retained, and will their consent be obtained for this?

(ii) If you intend to destroy certain data sets at the conclusion of the research:

(ii.i) Explain why this is appropriate

(ii.ii) How will you ensure that the data will be disposed of in such a way that there is no risk of its confidentiality being compromised?

9. Will payments to participants be made? **YES/~~NO~~**

(If YES, please state amount and whether payment is for out-of-pocket expenses, or a fee)

10. I confirm my responsibility to deliver the project in accordance with the Code of Practice on Research Ethics of the University of the Arts London (the University). In signing this form I am also confirming that:

a) The form is accurate to the best of my knowledge and belief.
b) There is no potential material interest that may, or may appear to, impair the independence and objectivity of researchers conducting this project.
c) I undertake to conduct the project as set out in the application unless deviation is agreed by the University and to comply with any conditions set out in the letter sent by the relevant College Research body and/or the University's Research Ethics Sub-Committee.
d) I understand and accept that the ethical propriety of this project may be monitored by the relevant College Research body and/or the University's Research Ethics Sub-Committee.

Signature of Student: _____ Date:___14.02.13_____

11. I support this project and have reviewed it with the applicant:

Signature of Director of Studies _____Date:___13.02.2013_____

Candidate comments on the indicative Ethics Guidelines for proposed research:

Ethical Approval of the research in response to point 3.2 of the UAL Ethics Approval Guide, which states that;

"If the research involves any of the following elements then the research is likely to have an ethical dimension for which approval must be obtained […]

- *The use of human tissue (defined in 5.4 below)*

5.4 ***Human tissue*** *is defined as material that has come from a human body and consists of, or includes, human cells. Consent is the fundamental principle of the legislation regarding the use of human tissue: the Human Tissue Act 2004 lists the purposes for which consent is required."*

The proposed research does not require consent under the legislation laid down in the Human Tissue Act 2004 which states that;

"7 Powers to dispense with the need for consent

(1) If the Authority is satisfied –

(a) that the relevant material has come from the body of a living person,

(b) that it is not reasonably possible to trace the person from whose body the material has come ("the donor")

(c) that it is desirable in the interests of another person (including a future person) that the material be used for the purpose of obtaining scientific or medical information about the donor, and

(d) that there is no reason to believe –

(i) that the donor has dies,

(ii) that s decision of the donor to refuse to consent to the use of the material for that purpose is in force, or

(iii) that the donor lacks the capacity to consent to the use of the material for that purpose,

it may direct that subsection (3) apply to the material for the benefit of the other person."

The cell lines that I foresee using will be anonymous and commercially available. However should it arise in the course of the lab work that it is desirable to use a cell line that has attached to it a need to obtain consent then this will be applied for before any research is carried out.

APPENDIX 7

RISK ASSESSMENTS

Note:
Alongside having the relevant Risk Assessments in place I have also undertaken safety training provided by Kings College London.

Courses completed:

- HSESTM01: Biohazard Laboratory Safety (Modules 1 & 2)
- HSESTM05: Risk Assessment for COSHH

GENERAL RISK ASSESSMENT FORM

KING'S College LONDON
University of London

1	RISK ASSESSMENT NUMBER		ISSUE NO.	

2	PERSON RESPONSIBLE FOR WORK (e.g. PRINCIPAL INVESTIGATOR)		
Name: Professor Lucy Di-Silvio		Position:	Professor
School: Dental		Division:	Restorative

3	PERSON CONDUCTING THE RISK ASSESSMENT		
Name: Miss Paula Coward		Position	Laboratory Manager
School: Dental		Date:	13 February 2012

4	LOCATION OF WORK ACTIVITY
Dental Clinical Research, Floor 17 Tower Wing, Room 17/11a (New tissue lab), 17/12 and 17/11	

5	ACTIVITY DESCRIPTION

Research Project: What if we use tissue engineering to redesign the body
Note: Each technique has its own risk assessment and COSSH as listed below.
For Description of methods please see the individual protocols.

Amy Congdon (Phd)

Materials
Human gingival fibroblasts, Stem cells (Msc), Osteoblast (HOS), Osteosarcoma (HOS) (Bioharzdous)

Cell culturing techniques
Trypsin Freeze Mix (DMSO/FCS)
Complete Media Trypan Blue (Toxic)
Phosphate Buffered Saline Virkon
70% IMS (Highly Flammable, Harmful)

Alamar Blue
Alamar Blue – Resazurin Sodium Salt (Irritant) PBS

MTT
Ethanol (Highly Flammable) DMSO
Thiazoly Blue Tetrazolium Bromide (MTT) (Irritant)

SEM
Note: Using Gluteraldehyde requires a lung function test.
Ethanol (Flammable)
Gluteraldehyde (Toxic) Hexamethyldisilazane (HMDS) (Highly Flammable & Corrosive)
Osmium Tetraoxide (Very Toxic)
Sodium Cacodylate (Toxic (poisonous cat1) Tannic Acid (Irritant)

Live Dead stain
Calcein AM Ethidium Homodimer (Irritant)

Equipment

Balance	Class 2 Cabinet	Centrifuge
Cell Counting Equipment	CO2 Incubator	
-80 Freezer	Fume hood	
Liquid Nitrogen Storage	Microfuge	Microscope/Fluorescence
Pipettes	Plate Reader	
Ph Meter	Shaker	Mixer

6 **AT RISK GROUPS**		
Type	Y/N	Describe additional precautions required (if any)
Maintenance workers		
Young persons		
Other (describe) Visiting PhD Student	Y	Under supervision of Trained personal.

7 **HAZARDS**			
	Present Y/N	Describe hazard or state whether a Specific Risk Assessment supplement is used (and attach)	Adequately controlled Y/N (refer to controls section 8B below)
Biological	Yes	Possible infectious material. Bara for tissue culture (sent to all users). "BARA cell culture 2010" Release of Infectious material from Safety cabinet.	Y
Chemical	Yes	Toxic & Harmful – inhalation, skin contact. Highly flammable – Fire. Corrosive – can cause burns to skin Irritant – Skin contact, inhalation. Also refer to relevant Safety data sheets.	Y
Physical	N		Y
Other (ergonomic)	Yes	Confined area in Tissue hood.	Y
Electrical	Yes	Electric Shock	Y
Liquid Nitrogen – Asphyxiant gas	Yes	Risk of asphyxiation. Risk assessment "Use of Liquid nitrogen"	Y
Centrifuge	Yes	Imbalance – possible injury to debris "COP for centrifuges"	Y

8 **CONTROL MEASURES**		
8A **HIERACHY OF CONTROL**		
Type	Used Y/N	Justification
Elimination	N	
Substitution	N	No substitutions

Engineering (local exhaust ventilation etc.)	Y	Fumehood. Microbiological safety cabinet.
Behavioural/Administrative (SSW etc)	Y	Standard Operating procedures for all techniques as listed on front of risk. Training in tissue culture and use of centrifuges, liquid nitrogen and safety cabinets.
Personal Protective Equipment	Y	Nitrile Gloves. Eye Protection. Howie laboratory coat (white & blue). For liquid Nitrogen Face shield and insulated gloves worn.
8B **CONTROLS IDENTIFIED**		
Type (for each hazard identified at 7 above a related control should be listed here)	In place Y/N	Comments
Biological - All Staff have Hep B. Use of Containment equipment. PPE. BARA for cell culture	Y	
Chemical - Following Written protocols as listed on front of risk. Use containment equipment ie fumecupboard. PPE. COSSH attached to individual method risks.	Y	
Ergonomic - Assess working in the confined space.	Y	Verbally told
Electrical - Assess electrical equipment before use	Y	Verbally told
Liquid Nitrogen - O2 monitors installed and instructions verbally and written instructions inside and outside room.	Y	
Centrifuge - SOP for use of centrifuge. Attached to centrifuge.	Y	

9	**INFORMATION, INSTRUCTION, TRAINING AND SUPERVISION (DESCRIBE COURSES AND/OR SPECIAL ARRANGEMENTS REQUIREMENTS)**
	Before starting any tissue work, basic instruction is given – using centrifuge, microbiological safety cabinet, general cell culture techniques as well as liquid nitrogen. This is recorded on persons training sheet.
	Other techniques are explained by the person supervising the student and they are given full instructions verbally as well receiving any relevant SOPS
	Only users who have health surveillance can use Glutaraldehyde

10 **MONITORING**		
Type	Required Y/N	Describe (include results of any monitoring carried out)
Maintenance	Y	Microbiological safety cabinets are tested every 6 mths with a KI test done once a year. Fume hood checked every 6 mths. Centrifuges are tested yearly.
Environmental monitoring	N	
Self inspection/reporting	N	
Health Surveillance	N	

11	**EMERGENCY PROCEDURES**	
Type		Describe
Spillages		Biological - Refer to Bara Tissue culture 2010 for spills. Refer to SOP on spills. If small spill mop with Trygene or virkon and dispose of any tissue in yellow bag. Follow up with 70% IMS. Chemical – likely to be small amounts.
First aid		Floor 17 First aiders: Peter Pilecki 020 7188 3874 Kathy Paterson 020 7188 7457 **All incidents and near-misses** should also be reported to the college via the incident reporting form. **Chemical Hazards:** Always take the MSDS data sheet when seeking medical advice.
Other (specify)		

12	**PROCESS RISK ASSESSMENT**
Overall risk rating (select one rating)	

RISK ASSESSMENT MATRIX

SEVERITY	Fatality	Medium	High	High	Unacceptable
	RIDDOR	Medium	Medium	High	High
	Moderate Injury	Low	**Low**	Med	Medium
	Minor Injury	Insignificant	Low	Low	Low
		Unlikely	Possible	Probable	Certain
		LIKELIHOOOD			

Justification for rating (describe reasoning for risk rating	Rated as low as long as protocols are adhered to. Techniques are listed at front of risk.

13	**RECOMMENDATIONS FOR FURTHER ACTION**		
Recommendation		Who by	When

14	**ASSESSMENT REVIEW**					
Review	Date	Assessor name (PRINT)	Assessor (signature)	Outcome of review Change/No Change	Managers name (PRINT)	Managers acceptance (Signature)
1						
2						
3						

Biological Agents Risk Assessment: Laboratory Work

Read associated guidance notes before completing this form: HSEPO2009(GF002)

Background Details

Assessor:	Miss Paula Coward	**School:**	Dental
Division:	Restorative Group	**Dept:**	Dental Clinical Research / Tissue engineering
Phone number: 020 7188 1791		**E-mail:** paula.coward@kcl.ac.uk	

Project title / Activity:
Tissue culture using Human cells (this includes various projects)

Local Biological Safety Supervisor / Advisor	
Proposed location of work	Room 17/12 & 17/11A (new tissue lab)
Proposed start date	On going

Summary of Assessment		**Date**	**Initials**
Hazard Group:	HG2	23/03/2010	
Containment Level:	CL2	23/03/2010	
Reference No:	0001		
Previous Reference No:			

Residual risks: Low / Medium / High *delete as appropriate*

Print names and emails, sign and date

Assessor
Please confirm that the information provided is, to the best of your knowledge, accurate and correct.
Miss Paula Coward / paula.coward@kcl.ac.uk

Departmental Biological Safety Supervisor
Please confirm that you have advised the Assessor during the completion of this form.

Head of Department
Please sign to approve the work is appropriate for the Department and that all relevant regulatory requirements are met.
Professor Richard Palmer / Richard.palmer@kcl.ac.uk

Date of next review:	**March 2011**

Member of the Biological Safety Committee (for Biological Agents that require HSE notification)
Please confirm that this BARA has been distributed and discussed by the School's BSC and a report has been circulated to the Assessor and the BSC members on the result of this review deeming it to be adequate.

College Biological Safety Officer (for Biological Agents that require HSE notification)
Please confirm that the appropriate regulatory body(ies) have been notified and appropriate School notified of outcome.

HSE Notification required:	Yes / No	**Notification sent:**	
HSE Approval required:	Yes / No	**Approval received:**	
DEFRA Notification (SAPO):	Yes / No		
Home Office Notification:	Yes / No		

1. General description of activities (including aims and overview of methods)

This BARA covers the routine culture of tissue culture cells, commercially purchased, gifted from other establishments,, primary cells for various experiments involving various materials, such as… Titanium, Hydroxyapatite (HA), Aliginates, Bone cement and Bioglass.

The experimental work these cells are then used for includes: Testing for biocompatibility and cell interactions – cytotoxicity, cell metabolism, apoptosis and bio functionality.

The research work is for projects investigating the following illnesses/conditions:
- Functionally graded scaffolds for Spinal Disc regeneration.
- Developing a tissue engineering strategies for bone, incorporating tissue specific stimulation factors.
- Optimization of bioreactive synthetic bone scaffolds

Vascularisation of tissue engineered scaffolds.
note that this list is not fully comprehensive and other research projects may be included at current or later dates.

2. Samples of unknown provenance or content (Adventitious Agents that may be encountered during activities)

As primary human cells are involved, there may be adventitious agents present such as HIV, Hepatitis, Toxoplasma.. However, the cells are taken from patients from lower risk demographic groups to minimise the likelihood of these agents being present.

3. Biological Agent(s) – Deliberate Use

a. Name and type	b. Genotypes and key features	c. ACDP group or locally assigned Hazard Group (if available)	d. ACTSA Schedule 5 (if appropriate)
Human Fibroblast cells (1BR3)(HDF1)	**Screened**	**HG1**	
Human THP1 Monocyte (ecacc)	**Screened**	**HG1**	
Human Skin Fibroblast cells 142BR (ecacc)	**Screened**	**HG1**	
Human Dental Pulp cells (Pharmakine)	**Screened**	**HG1**	
Human mescenchymal stem cells (HMSCpt) (Cambrex)	**Screened**	**HG1**	
Human Astrocyte cells (Sciencell)	**Screened**	**HG1**	
Hob Aveolar Bone	**Unscreened**	**HG2**	
Hos Cells (TE85)	**Screened**	**HG1**	
Hob cells	**Unscreened**	**HG2**	
LA1-55 Fibroblast like	**Screened**	**HG1**	
HMSCB Bone stem cells	**Screened**	**HG1**	
HUVEC	**Screened**	**HG1**	
HOBC HOBSV40	**Unscreened**	**HG2**	
PSC Dental Pulp	**Unscreened**	**HG2**	
Chondrocytes NHAC-kn	**Screened** **Note: Screened HG1 are confirmed by supplier** **Unscreened HG2 are donated and from patients - primary cells**	**HG1**	

4. Consideration of potential hazard caused by biological agents to human health		
a. Amounts to be used		
Typical 2 - 4 x 75cm flasks per passage 2x 175 cm flasks per passage	Maximum 6 – 8 x 75 flasks per passage 4 x 175 flasks per passage	Amounts stored 1ml aliquots of cells, 1 -2 vials per passage
Comments Cells stored in gas phase of liquid nitrogen and logged in book with location in liquid nitrogen.		
b. Routes of exposure		
Skin Aerosols – inhalation Splashes		
c. Consequences of exposure		
In most cases, non-penetrative exposure will not have any consequence to operators as the cells are non-invasive and will rapidly die on the skin surface. In the event of inoculation, e.g. via splashes to mucosal surfaces, the cells are likely to be identified by the operator's own immune system as foreign and consequently cleared.		

5. Minimising risks from biological agent(s) – Initial assessment
a. Substitution
Not possible, the cells are low hazard and there are no alternative systems currently available.
b. Reduction of exposure (Engineering controls)
Handled in microbiological safety cabinet and tissue work carried out in tissue culture lab. The lab is located on a limited access floor and operates at CL2.
c. Procedures for Safe System of Work (Procedural controls)
All staff and postgraduate students are fully trained to work with human cells, BSc (undergraduates) are supervised. Local rules covering tissue culture in place Standard operating procedures for various techniques
d. First Aid and treatment in the event of exposure
Wash the area with water, encourage any penetrative wounds to bleed. Contact Occupational Health and/or proceed to A&E.
e. Procedure in the event of spillage
Likely to be within a class II Microbiological Safety cabinet – so wipe with trygene and 70% IMS. Outside the MSC, depending on the volume, either: a. for large (~25-50ml) volumes, pour Haz-Tab granules onto the spill, allow to absorb, sweep up to create minimal dust agitation, and place in biohazardous waste. Wipe the affected area with trigene and 70% IMS. b. for small volumes (>25ml), wipe with trigene and then spray with 70% IMS
f. Minimum requirements for personal protective equipment
Laboratory coats (Blue Howie) and nitrile gloves
g. Likelihood of exposure with controls in place
Unlikely to occur.

6. Specify any other control measures to be used including waste and product inactivation and details of storage and transport
Waste media is placed in a virkon solution (1 tablet in 500mls water) for a minimum of 1 hour. **All flasks, tubes that come in contact with cells are autoclaved at 121 °C for 15 minutes and yellow bagged.** **Other items are yellow bagged and pipette tips and pipettes are put into a yellow sharps bins.** **All yellow bag waste goes via the yellow waste route of the Trust.**

7. Residual risks
Low

8. Personnel involved		
a. Names	b. Occupational Health screening (if applicable)	c. Qualifications and relevant experience
Laboratory Manager Undergraduate students Post Docs Post graduates	All will be complete pre-employment questionnaires prior to commencing employment within the department.	Fully trained Supervised Fully trained Fully trained

9. Other personnel that may be affected
Possible – anyone else entering the labs during working hours that should not be in the labs without reporting to the lab manager. Cleaners may enter the laboratory after hours but are told not to touch incubators/freezers with cells. Maintenance personnel may enter the laboratories with the lab manager's authority but TC work will either be curtailed for their visit or will be done to avoid the area that the personnel are working in.

10. Additional Health Provisions required (if applicable)
Personnel working with primary human cells will be offered hepatitis B vaccination.

11. Assignment of Hazard Group and Containment Level	**HG:** 1 & 2	**CL:** 2
Additional requirements for safe operation.		

APPENDIX 8

SEACELL MATERIAL DATA SHEETS

Product data sheet SeaCell™ 1.7 dtex / 38 mm

Cellulose fiber with incorporated seaweed (Ascophyllum nodosum) produced according to the Lyocell – process

Fibre composition in conditioned state (% by weight):

Cellulose	≥ 84 %
Seaweed powder	5 %
Fiber finish	0.32 %
Moisture	≤ 12 %
Appearance	light brown

Average textile physical fiber data:

Titer	d'tex	1.7
Cut length	mm	38
Tenacity dry	cN/tex	29
Elongation dry	%	11.2
Tenacity wet	cN/tex	25
Elongation wet	%	16,1
BISFA wet modulus	cN/tex/5%	7,6

The used cellulose is wood pulp, produced from eucalyptus.

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Internet: www.smartfiber.de

Rudolstadt, April 2016

Product Data Sheet

SeaCell™MT 1.7 dtex 38 or 60 mm

(based on Modal Technology)

Cellulose fiber with incorporated seaweed (Ascophyllum nodosum) produced according to the modified viscose-process

Fibre composition in conditioned state (% by weight):

Cellulose	≥ 83 %
Seaweed powder	4 %
Fiber finish	0.3 %
Moisture	12 %
Appearance	light brown

Average textile physical fiber data:

Titer	d'tex	1.7
Cut length	mm	38 / 60
Tenacity dry	cN/tex	≥ 25
Elongation dry	%	11-14
Tenacity wet	cN/tex	≥ 13
Elongation wet	%	11-14
BISFA wet modulus	cN/tex/5%	≥ 4

Cellulose is wood pulp made out of beech tree.

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E-Mail: mail@smartfiber.de
Internet: www.smartfiber.de

Rudolstadt, December 2016

SeaCell™

time to relax

English

THE POWER OF SEAWEED IN A FIBER

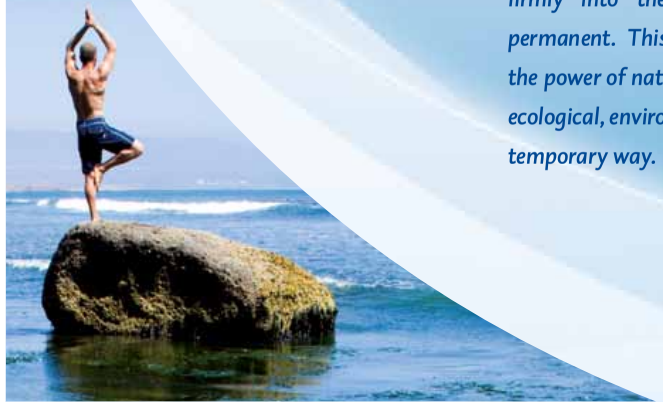
SeaCell™

The wellness fiber with the power of the sea

"All life comes from the sea." Hippocrates knew this more than 2,000 years ago. The SeaCell™-idea is based on this knowledge – and it is quite simple: The natural and pure nutrients of the sea are good for us and for our skin.

Their beneficial qualities are the basis of the SeaCell™-fiber, protecting the skin and promoting good health. It employs the elemental power of seaweed, the revitalizing, multitalented life form that carries our genetic code within it.

Our unique SeaCell™-fiber combines cellulose with seaweed. What is remarkable is that the seaweed is embedded firmly into the fiber: The effect is permanent. This way, SeaCell™ brings the power of nature back to people – in an ecological, environmentally friendly and contemporary way.



Seaweed – nutricious since primordial times

Seaweed is the "fuel of the seas". Just one kilogram of dried seaweed contains the active agents of more than 100,000 liters of sea water – one good reason to employ it in SeaCell™-fibers. With its abundance of nutrients, seaweed stimulates the organism and has a healing effect. Seaweed from Iceland contains more mineral salts and vitamins than any other natural product and is rich in amino acids, iodine, trace elements and much more.

Seaweed's protective effect for the skin and its anti-inflammatory properties has long been employed for our well-being – from traditional Chinese medicine to modern treatment methods. Seaweed is a valued addition to foods and cosmetics, because it strengthens the immune system and reduces blood sugar, regulates circulation, promotes digestion and revitalizes skin, hair and nails.

Active ingredients from a unique ecosystem

The brown algae (ascophyllum nodosum or knotted wrack) embedded in the SeaCell™-fiber comes from the cold, pure fjords of Iceland. The slopes of these sea arms are sparsely settled, and their untouched nature is a paradise for wildlife. The seaweed is full of minerals that it draws from the geothermal sea water – enriched with vital substances, free of contaminants and of the highest quality.

Naturally effective

Protection & care with seaweed

Skin is a multifaceted organ that protects the body from harmful environmental influences. The SeaCell™-fiber was developed to care for and protect our skin.

Its most important building blocks are the nutrients contained in the knotted wrack of Icelandic fjords. It is harvested and processed in a gentle, sustainable manner to promote its renewal and to maintain its biological value.

Among other things, these brown algae offer a large quantity of vitamins and minerals, such as magnesium and calcium as well as the active ingredient fucoidan, which constrains the growth of tumor cells. It is effective against influenza viruses and high cholesterol levels, relieves skin diseases, and contributes to the skin's healing process. Antioxidants are also a defense against free radicals – protecting against skin damage.

Brown algae …

… activates cell regeneration

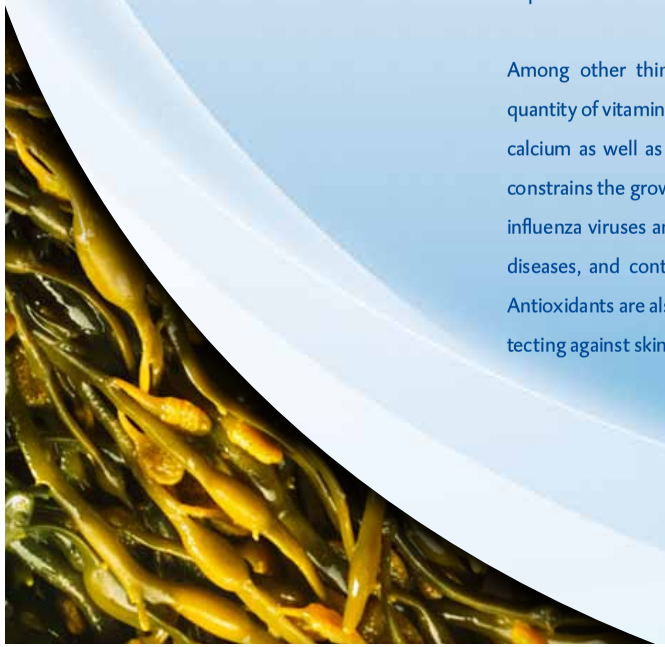
… re-mineralizes the skin

… limits inflammation, soothes itchiness

… performs successfully in the treatment of neurodermatitis and psoriasis

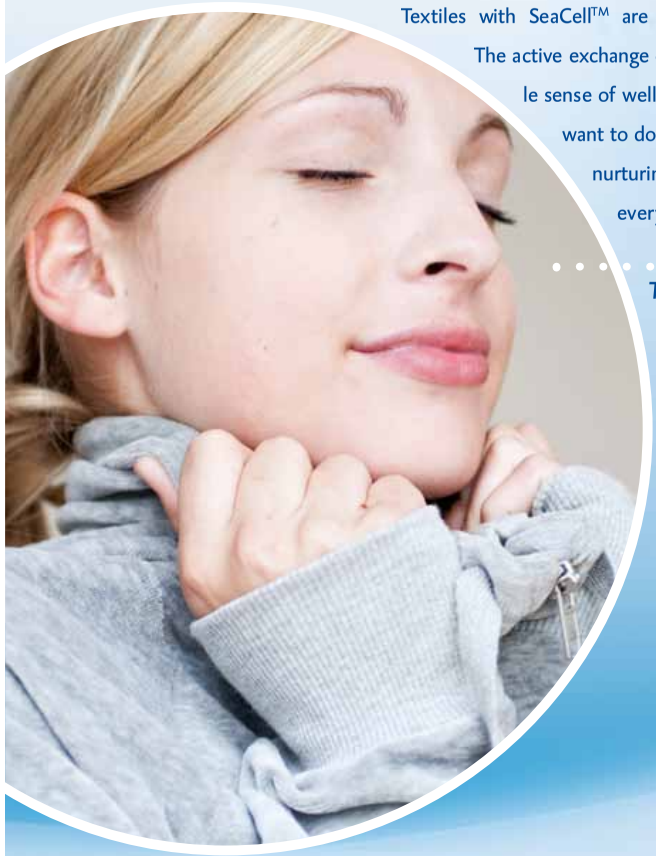
… protects against free radicals

… has a detoxifying, purifying effect



Softness

The secret of SeaCell™-fiber



Textiles with SeaCell™ are unsurpassed for their especially cuddly and soft feel. The active exchange of substances between fiber and skin provides a noticeable sense of well-being – the typical SeaCell™-effect that you would never want to do without again. The seaweed in the fiber has a calming and nurturing effect – so the soul as well as the body can recover from everyday stress: **SeaCell™ – time to relax.**

Thanks to the special combination of extraordinary softness, gentle care, and protection for your skin, SeaCell™ brings you the best nature has to offer. In doing so, the fiber has no cytotoxic effect. Even sensitive skin shows no adverse reactions. So in terms of skin physiology, SeaCell™ can be classified as harmless.

Softness

Minerals & more

Miracle cures for the skin

Your skin needs nutrients to stay healthy and beautiful. Mineral substances and trace elements are important, for example, since they invigorate your metabolism. In addition they have a positive impact on cell renewal, water balance, the healing of wound sand protect from the sun. Amino acids have a smoothing effect, while vitamins support the natural protective role of the skin and protect it from free radicals.

All these nutrients are present in the selected brown algae in SeaCell™ to a high degree. Your skin benefits from their valuable effects: Due to the natural moisture of the skin, the vital substances in the seaweed are set free when the fibers are worn. Their beneficial effect can therefore unfold over time – even after many washing cycles.

Beneficial nutrients in brown algae:

- *Minerals: e.g. magnesium, calcium, potassium and phosphorus*
- *Trace elements: mainly iron and iodine*
- *Amino acids: e.g. glutamic acid, histidine and alanine*
- *Vitamin: B, A and E*

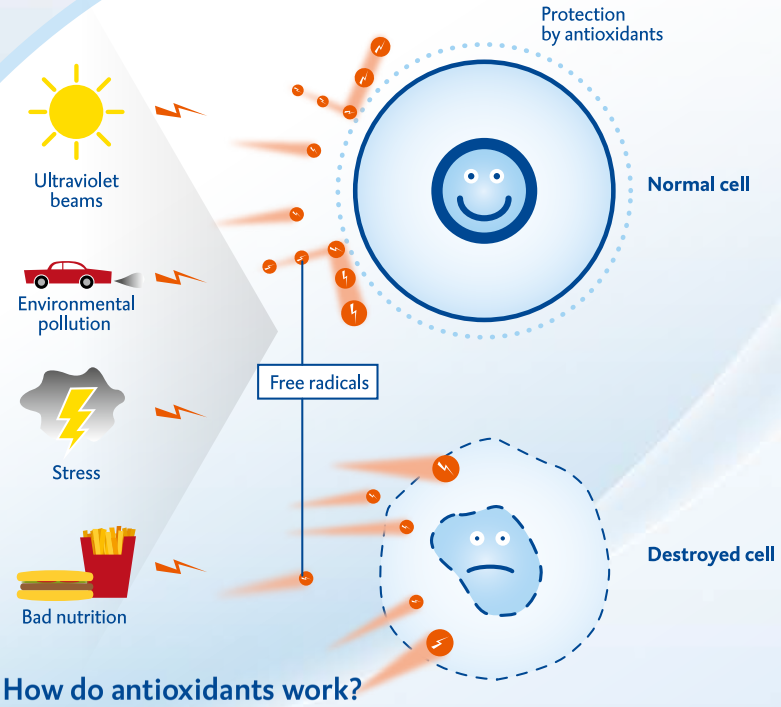
Antioxidants

Protecting against free radicals

The nutrient-rich knotted wracking SeaCell™ doesn't just let you feel the sea on your skin: It also has a property to effectively combat free radicals.

It's true that free radicals are continually produced in our bodies as natural metabolic products – but bad nutrition, stress, and environmental exposures can lead to their uncontrolled increase.

The body can no longer regulate this onslaught on its own: the free radicals disrupt important functions in the body and damage skin and genetic material. This can result in serious illnesses. But nature has developed an effecti-ve remedy: Antioxidants such as vitamins and minerals are abundantly available in brown algae and SeaCell™-fibers.



How do antioxidants work?

The body produces an excess of free radicals due to various external and internal factors. They attack cell membranes and vital proteins, making cells susceptible to ailments. Antioxidants – certain minerals, vitamins, enzymes, and plant materials – protect the skin from free radicals. The effectiveness of the seaweed in SeaCell™ in catching free radicals has been confirmed by the ABEL® antioxidant test at the renowned University Clinic of Jena.

Tested

The SeaCell™-effect

After intensive research and with the development of SeaCell™, it has become possible to introduce a fiber made of renewable materials that releases its beneficial ingredients directly and sustainable onto the skin. Numerous tests at various institutes and facilities are confirming its quality – and are guaranteeing a lasting SeaCell™-effect.

SeaCell™ – tested and honored:

- The ProteinAnalysis Center of the Bingen University of Applied Sciences has determined its amino acid content.
- The CYTOX test lab has attested to its cytotoxic harmlessness.
- Tests at the University Clinic of Jena and the ITV Denkendorf Institute have demonstrated that the fiber induces no allergic reactions in sensitive skin.
- The University of Jena has verified the radical-trapping properties of SeaCell™-fibers based on ABEL®.
- Awarded the EU Ecolabel and the OEKO-TEX® standard 100 seal by ÖTI, authorized for infant products, confirming its exceptional environmental friendliness.

FACHHOCHSCHULE BINGEN
University of Applied Sciences

CYTOX

CONFIDENCE IN TEXTILES
Tested for harmful substances
according to Oeko-Tex® Standard 100
41707 OeTI

A visible promise of quality

It is not just the SeaCell™-fiber itself, but even the textiles made from these special fibers that must again pass various tests. This is the only way to guarantee the health-promoting effect of the nutrients from the active exchange of substances between fibers and skin.

For this reason, all the textiles are again tested for their SeaCell™-fiber content after their completion. It is only when the products meet all the criteria that they are awarded the SeaCell™-label as their quality seal – and, with a special tag, they can be recognized as a product with noticeable function and real additional benefit.

The SeaCell™-label as quality seal

Quality

Forward-looking

Modern technology, employed with an awareness of nature

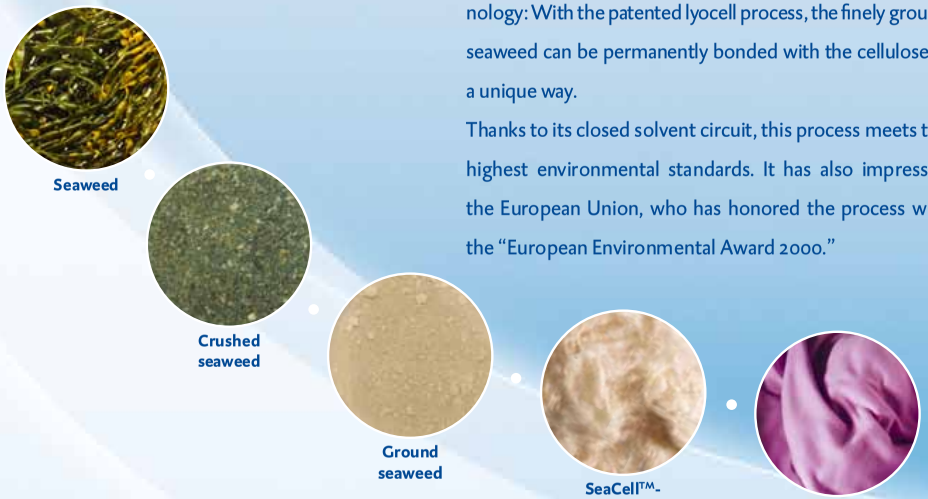
SeaCell™ is well-being for the skin. SeaCell™ means: immersing yourself and feeling great – day and night. The SeaCell™-brand stands for regeneration and lifestyle and brings some quality of life back to the stressful daily routine. That precisely corresponds with the expectations of today's modern, active customers. They want natural textiles with a positive effect on their skin – which SeaCell™ provides.

One foundation of the fiber's success is its innovative technology: With the patented lyocell process, the finely ground seaweed can be permanently bonded with the cellulose in a unique way.

Thanks to its closed solvent circuit, this process meets the highest environmental standards. It has also impressed the European Union, who has honored the process with the "European Environmental Award 2000."

SeaCell™ – Technical data			
Titre	dtex	1,7	6,7
Cut length	mm	38	60
Tenacity	cN/tex	≥ 35	≥ 28
Tenacity wet	cN/tex	≥30	≥ 21
Elongation	%	13	14
Elongation wet	%	17	17
Wet modulus	cN/tex	≥180	≥ 120

Quantities to be used: To achieve the presented effects, at least 23 % of SeaCell™ need to be used in the end product.



Seaweed

Crushed seaweed

Ground seaweed

SeaCell™-fiber

Fabric with SeaCell™

From nature to clothing:
The dried seaweed is crushed coarsely, ground and simultaneously introduced into cellulose fiber, from which materials for an extremely wide variety of textiles are manufactured.

Comfortable and high-quality:
Modern textiles have to meet more than just ecological standards – wearing comfort, quality and added benefits are important to consumers in equal measure.

All-around usability, well-suited to combinations

The SeaCell™-fiber is ideal for an extremely wide variety of applications – from stylish clothing to home textiles. It is suited for any textile that comes into contact with the skin, providing care, protection, and wellness. The fiber is perfect for physical activity due to its breathability and the skin-care effect of the seaweed.

The fiber represents a healthy mix of comfort and functionality. It offers numerous opportunities for processing and can be wonderfully combined with other fibers in knits, woven fabrics, and fleeces.

This textile product is high quality and comfortable to the touch, and even synthetic blends feel soft and totally natural.

Opportunities to use SeaCell™:

- *Home textiles such as bed linens, pillows and blankets*
- *Sleepwear and underwear*
- *Sport clothing*
- *Leisure clothing*
- *Child and infant clothing*

smartfiber AG

Using nature's know-how

smartfiber AG's business concept is quite simple: Since its founding in 2005, the company based in Rudolstadt, Thüringen, has relied on a high standard for quality, coupled with creative ideas and a nature-oriented approach. And just like Charles Darwin, smartfiber AG is convinced that "Anything against nature, won't abide for any length of time". Since 2005, smartfiber AG has championed patented, innovative, nature-based high-tech fibers produced exclusively for the company by Lenzing AG in Austria.

More about smartfiber AG.

Visit us on Facebook.

smartfiber AG
intelligent world of fibers

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APPENDIX 9

CONTRIBUTIONS TO SYMPOSIUMS AND CONFERENCES

EXHIBITIONS:

NATURE: COOPER HEWITT DESIGN TRIENNIAL WITH CUBE DESIGN MUSEUM

May 2019 - January 2020

Dual exhibition at:

Cooper Hewitt Smithsonian Design Museum, New York, USA

Cube Museum, Netherlands

Spare Parts

Feb - May 2019

Science Gallery, London, UK

La Fabrique du Vivant

Feb - April 2019

Pompidou Centre, Paris, France

Coded Couture

09.07.2016 - 04.09.2016

On show at the following venues:

+ Pratt Manhattan Gallery, New York, USA

+ Ulrich Museum of Art, Kansas, USA

+ Tufts University Art Gallery, Boston, USA

+ Oklahoma Contemporary Arts Center, Oklahoma, USA

+ CAM | Contemporary Art Museum, Raleigh, USA

+ Ruth Funk Center for Textile Arts, Melbourne, USA

Hybrids: Interspecies Collaboration in Craft and Design

30.06.2016 - 24.07.2016

The National Centre for Craft and Design, Lincolnshire, UK

Utopia Lab

09.06.2016 - 28.08.2016

Somerset House, London, UK

Biological Atelier: The Showroom | SOLO SHOW

22.02.2016 - 28.02.2016

Manchester Craft & Design Centre, Manchester, UK

OFF THE GRID - Design Visions for Economy

22.10.2015 - 28.02.2016

Munich Creative Business Week, Alte Kongresshalle, Munich, Germany

BIOFABRICATE 2015: Design Lab Exhibition

28.05.2015 - 31.05.2015

Microsoft Headquarters, Times Square, New York, USA

Biodesign

07.01.2015 - 040.22015

Curated by William Myers for Home & Style Fair, Bursa, Turkey

Crafting Anatomies

07.01.2015 - 04.02.2015

Bonnington Gallery, Nottingham, UK

BIOFABRICATE 2014

04.12.2014

Microsoft Headquarters, Times Square, New York USA

'Restless Futures'

13.09.2014 - 20.09.2014

London Design Festival, Lethaby Gallery Central Saint Martins

'Material Change' by Pringle of Scotland and Disegno

13.09.2018 - 20.09.2014

London Design Festival, Pringle of Scotland Flagship Store, London, UK

'Big Data: Designing with the Materials of Life'

23.01.2014 - 13.02.2014

Lethaby Gallery Central Saint Martins

'Design Beyond Making', by Vectors

01.11.2013 - 10.11.2013

Protein Gallery London

'ALIVE: New Design Frontiers'

26.04.2013 - 01.10.2013

Espace Fondation EDF, Paris

SPEAKING:

Nature Salons: Encouraging Growth

10.05.2019

Invited panelist with Richard Beckett, and Marcos Cruz in conversation with Andrea Lipps, Associate Curator of Contemporary Design at the Cooper Hewitt, New York, USA.

'Tissue Engineered Textiles'

27.03.2018

Invited Speaker, Ruth Funk Centre for Textile Arts, Florida Institute of Technology, USA

Maison/0: The Other Way

02.02.2018

Central Saint Martins, UAL, London

"Tissue Engineering: a multidisciplinary approach"

26.04.2016

Crick Chat Series, run by The Francis Crick Institute, held at Central Saint Martins, London, UK

"Fashion + Technology + Sustainability = Future Reality?"

14.04.2016

FashTech Summit, London, UK

"Will the Next Alexander McQueen Be a Biologist?"

09.02.2016

Brooklyn Fashion & Design Accelerator, Brooklyn, New York, USA

Bio Salon

03.12.2015

Futuro House, Central Saint Martins, UAL, London

"Curiosity Box"

24.07.2015

Festival of Curiosity Headline Event, Mansion House, Dublin, Ireland

"DESIGN FUTURES - Fashion, Body & The Mind"

23.07.2015

Festival of Curiosity, Smock Alley Theatre, Dublin, Ireland

'Biotextil' Symposium

18.05.2015

National Museum of Ethnology Leiden, Netherlands.

'Future Fashion: Growing Materials in the Lab'

20.01.2015

Fashiontech Berlin Summit, Germany

BIOFABRICATE Summit

04.12.2014

Microsoft Headquarters, Times Square, New York USA

'Transitions Conference'

26.11.2014 - 27.11.2014

Huddersfield University, UK

'Make:Shift'

20.11.2014 - 21.11.2014

Crafts Council Conference, Ravensbourne University London

Hybrid Talks 'Nature – Material – Culture: Practice and understanding of biotechnology'

30.10.2014

Berlin, Germany

'Wearable Futures Conference'

10.11.2013 - 11.11.2013

Ravensbourne University London

'Colloquium: Cutting: On the Fabric of the Human Body'

01.05.2013

Kingston University, London